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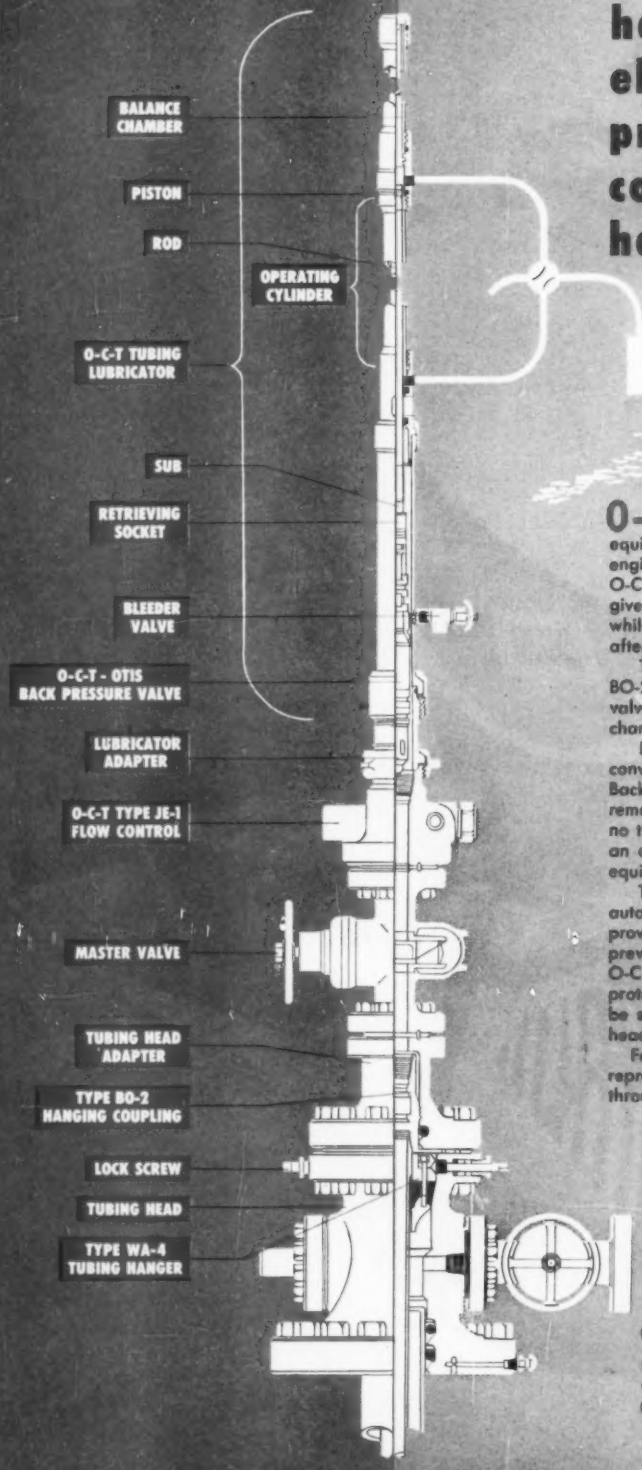

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On the Cover: Offshore operations in North Texas — An aerial view of the Big Mineral field shows the system of earthen drilling platforms in Lake Texoma. An article by J. M. Garlick, Shell Oil Co., on the exploitation of the Big Mineral field begins on page 9 of this issue.

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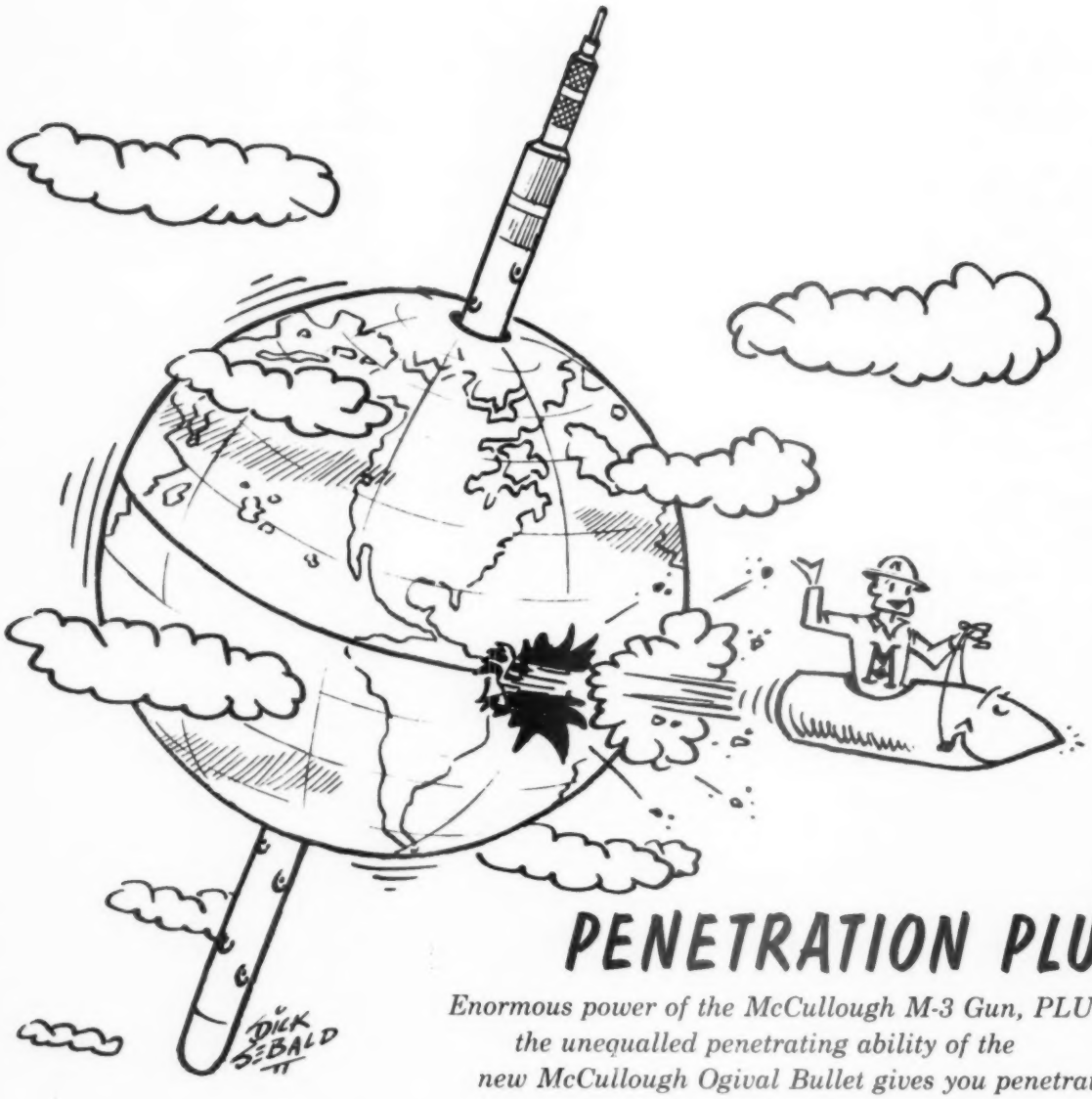

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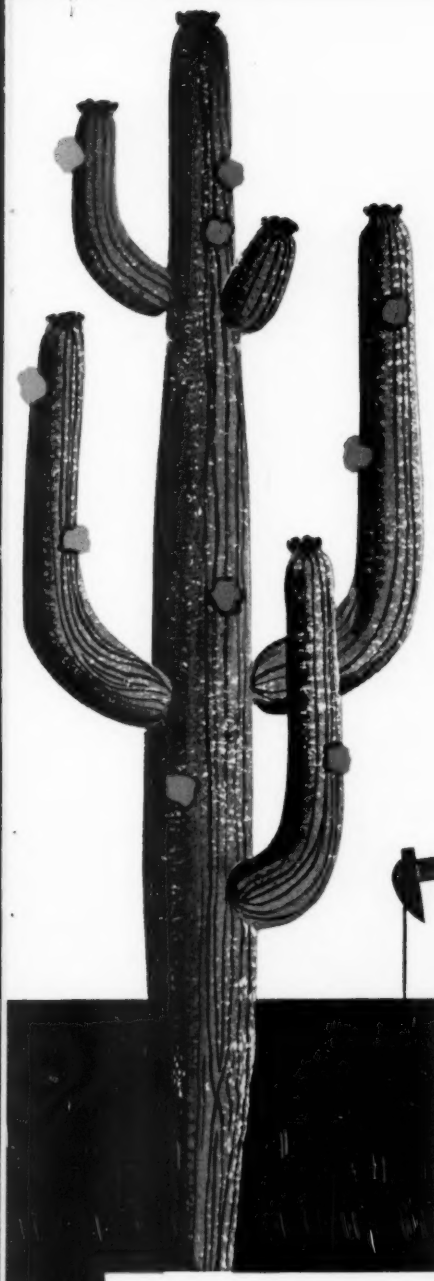

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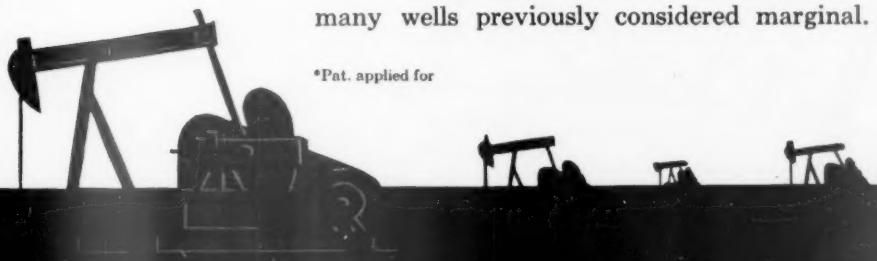

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FEATURE ARTICLE

BIG MINERAL FIELD EXPLOITATION — A CHALLENGE to ENGINEERS

J. M. GARLICK
MEMBER AIME

SHELL OIL CO.
WICHITA FALLS, TEX.

Abstract

Exploitation of the Big Mineral field, located in North Central Texas, has been and continues to be a challenge to the engineer. The field is partially inundated by the waters of Lake Texoma. Multizone oil production ranging in depth from 3,600 to 10,200 ft is found in steeply dipping Pennsylvanian and Ordovician sediments. This paper brings into sharp focus the contributions of each branch of engineering to the solution of the major development and production problems.

Based on comprehensive data gathered on early development wells, it was determined that the drilling of separate wells to each of six production horizons was justifiable. To accommodate wells drilled in the lake bed 32 earthen drilling platforms with earthen access roadways were planned and constructed. Each platform was of sufficient size to allow the drilling of from one to three wells. In order to combat crooked hole conditions and stimulate drilling rates "large size drill collars" and "jet bit" programs were followed. Hydraulic artificial lifting methods, remote control of flowing wells, and semi-automatic centralized storage facilities were provided so that production would not be interrupted should the earthen platforms be inundated by the lake.

Introduction

As in most industries management in the petroleum industry is relying more and more upon engineers to plan development and production projects. Where in the early days perhaps one engineer handled all engineering problems, companies now employ a staff of 10 or more engineers, each with a different engineering background and responsible for a specific phase of engineering. It therefore follows that if an integrated engineering plan is to be accomplished, all of these engineers must be consulted, work together in an atmosphere of understanding, and contribute their part to the master plan. This paper has been written for the purpose of showing how these principles have been applied to the variety of problems involved in the exploitation of the Big Mineral field. Consequently, no attempt is made to present a complete history of the field. Instead, only the major problems are highlighted. Special emphasis is placed on each engineer's contribution to the solution of these problems.

The general field data presented herein cover all properties in the Big Mineral field; however, the engineering plans and solutions to the various drilling and production problems are those used by Shell Oil Co. in developing their properties in the field.

The Big Mineral field is located in western Grayson County, Tex., approximately 12 miles northwest of Sherman, (Fig. 2). Oil production is found in sandstones ranging in depth from 3,600 to 10,200 ft. As may be seen in Fig. 3, the field is situated partly on the banks of Lake Texoma and extends about one-half mile into the Big Mineral arm of the lake.

Fig. 1 — A typical drilling well on an earthen platform in the Big Mineral field, Lake Texoma.

[1]References given at end of paper.

Manuscript received in Petroleum Branch office on Aug. 9, 1954. Paper presented at Petroleum Branch Fall Meeting in San Antonio, Oct. 17-20, 1954.

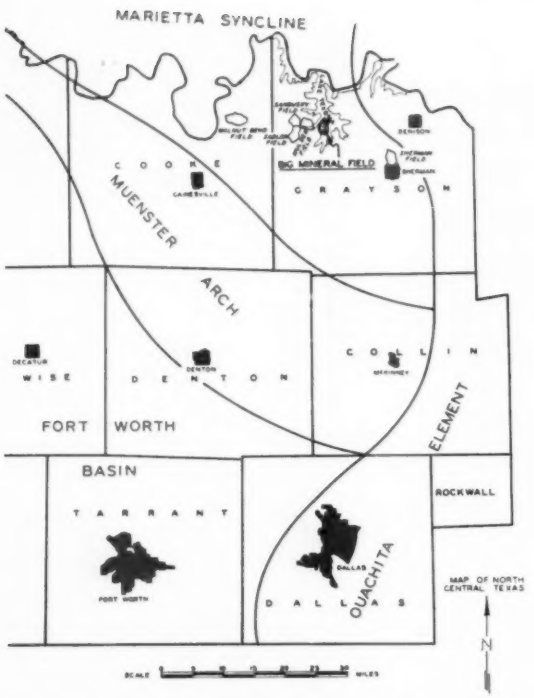


Fig. 2 — Geological and index map showing location of Big Mineral field.

Initial Development

The Big Mineral structure is a northwest-southeast trending elongated anticlinal feature situated on the southwest flank of the Marietta Syncline, as shown in Fig. 2. Pennsylvanian sediments ranging in thickness from 3,000 to 13,000 ft are known to exist in the area. The complete Pre-Pennsylvanian sedimentary section, however, has not been penetrated by the drill.

Development of the Big Mineral field was initiated in March, 1951, with the drilling of Lynn Drilling Co., et al-Barnes No. 1 on the west flank of a seismic prospect. This well was drilled to and established condensate production from the Oil Creek formation at a depth of 10,200 ft. Oil production was also established in Pennsylvanian sandstones at 3,600 ft, designated "Little" zone, and at 5,200 ft, designated "Barnes". It was realized, therefore, very early in the development phase that this would be a multiple zone oil field. However, the probable number of productive members was not recognized until Shell-Green No. 1, located near the crest of the prospect, was drilled some nine months later. This well also penetrated the Oil Creek sandstone and gave evidence of additional hydrocarbons in a series of Pennsylvanian sandstones from 5,650 to 6,150 ft, at 6,340 ft, and at 6,400 ft. After drilling these two deep tests, one on the west flank and the other on the crest of Big Mineral prospect, the scope of the exploitation problem was recognized.

Exploitation of this multizone field was further complicated by the fact that at least part of the field would extend beneath the waters of Lake Texoma, thus requiring special drilling and producing techniques.

Drilling Program

The multizone character of this field demanded that an organized drilling program be established as soon as practicable. The production geologists and reservoir engineers had the immediate job of assembling subsurface and performance data so that eventually a spacing pattern could be established.

Since development of the Little sandstone was underway before it was recognized how many producing reservoirs would be involved, drilling was on a 20-acre density with wells drilled in the northeast and southwest quarters of each 40-acre tract. Although this spacing was similar to that normally followed for comparable reservoirs and depths in North Texas, the pattern was such that it could easily be converted to closer spacing should that be considered advisable at a later date.

At this point only the Little sandstone at 3,600 ft and the Barnes at 5,200 ft were confirmed as being oil bearing. It was recognized that a number of oil shows were still untested below the Barnes and above the Oil Creek condensate accumulation. In order to test this unknown section, the detail plan was to drill a 7,000-ft well in the northwest quarter of each 40-acre tract with completion being made in the Barnes sandstone and a 7,000-ft well in the southeast quarter with completion in a deeper accumulation. Drilling the additional hole required in this program was expensive, but the information gained far outweighed the cost. Few drill stem tests were conducted in the first two deep wells drilled in the field; hence, the productivity of the apparently hydrocarbon bearing members recognized in drill cuttings and from electric logs was not proven. With the initiation of the deep well drilling program a concerted effort was made to procure usable subsurface and reservoir data for each productive zone. This was accomplished through drill stem tests and a planned coring schedule. It must be recognized that at this stage of development of the Big Mineral field no rigid program was being employed. General objectives had been outlined and a well pattern developed which were designed to give maximum flexibility while information was being gathered that would enable the engineers to set up a firm exploitation program.

After the drilling of about 16 deep wells sufficient data were available to make an engineering evaluation of the field. The tools used by the subsurface and reservoir engineers in making their interpretations were core analyses, drill stem test data, electric logs, bottom hole pressure built-up data, and PVT analyses of hydrocarbon samples. A workable grouping of the various oil bearing sandstones encountered throughout the Pennsylvanian system was now possible. Sandstones with similar characteristics such as sand character, pressure, and type of hydrocarbons present were grouped and designated a zone.

The type log in Fig. 4 shows the accepted reservoir designations. It may be noted that the six separate reservoirs are designated as Little sandstone zone at about 3,600 ft, Barnes sandstone at 5,200 ft, "S" sandstone at 5,800 ft, "U" sandstone at 6,300 ft, "V" sandstone at 6,500 ft, and Oil Creek below 10,000 ft. These reservoir designations were accepted by the Railroad Commission of Texas along with field rules for each of the zones. Field rules provide for 20-acre spacing for the Little sandstone and 40-acre spacing for the Barnes, "S", "U", and "V" sandstones.

The present structural concept and extent of production of the six reservoirs in the Big Mineral field are reflected by the structure maps in Fig. 5. Characteristics of the various reservoirs have been determined and are also shown in Fig. 5. Initial well productions range from 100 to 550 B/D.

The drilling pattern currently being followed is to drill two Little sandstone wells on each 40-acre tract with one well in the northeast and one in the southwest quarter. One Barnes sandstone well is drilled in the northwest quarter and one "S" sandstone well in the southeast quarter of each 40-acre tract. Because of the limited extent of the "U" and the presence of a gas cap in the "V" sandstone, a uniform well pattern is not possible in these two zones.

The plan of development in Big Mineral so far has withstood a rigid test. There has been only one dry hole drilled and only isolated cases where a well had to be recompleted in a shallower horizon by reason of its objective zone being found non-productive. This success is attributed mainly to the fact that the deep wells were drilled first and the shallower wells infilled after sufficient subsurface control had been established.

Lake Drilling Platforms

It became apparent early in the development program of the Big Mineral field that the productive area would extend into the Big Mineral arm of Lake Texoma. Therefore, concurrently with the planning of the drilling program, some method of drilling and producing wells in a water inundated area had to be formulated.

Lake Texoma is an artificial lake resulting from the construction of the Denison Dam across the Red River. The lake is used to store water for generating electrical energy and for flood control. The over-all project is under the supervision of the U. S. Corps of Engineers. In addition, the Big Mineral arm of the lake is included in a U. S. Wildlife Refuge.

From detailed records maintained by the Corps of Engineers it was found that a large fluctuation in the lake level occurred every year. A study of the data showed that the development area in the Big Mineral arm, which is of low topographic relief, would normally be at various stages of inundation and could be dry for short periods of time. Maximum lake level has reached 629 ft above sea level; however, attempts are made to maintain the level at or below the 617-ft power pool level by use of flood gates.

After mechanical engineers had made a study of all lake performance data and correlated these data with the requirements of the drilling program, it was concluded that the method finally decided upon to accommodate drilling in the lake would have to satisfy the following requirements: (1) Provide drilling sites on each 10-acre tract for wells ranging in depth from 3,600 to 10,200 ft; (2) Provide dependable access to well sites, both while drilling and during the producing life of the field; (3) Be acceptable to U. S. Corps of Engineers and U. S. Wildlife Department; and (4) Be economic.

Taking into account four plans of approach to the problem, it was concluded that the method of constructing earthen drilling platforms and earthen access roadways more nearly met all of the above requirements. Three alternate methods were considered. First, drill wells when the lake level was low. This was considered

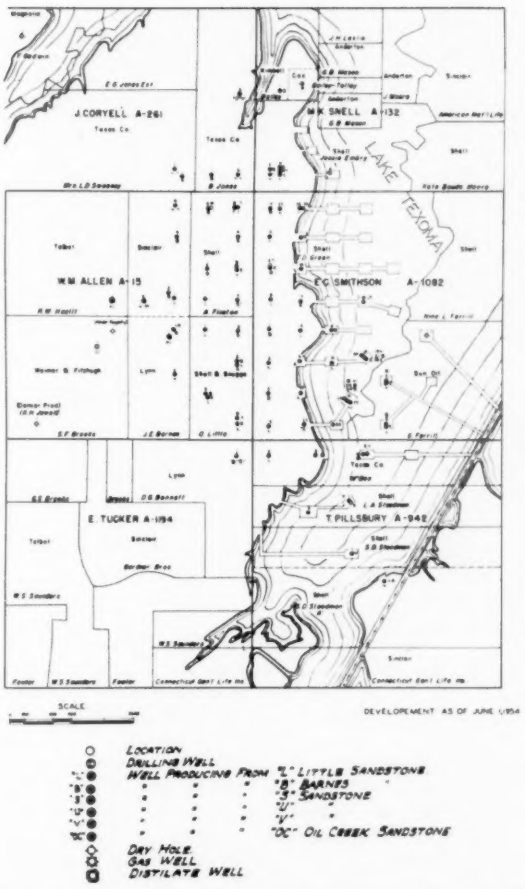


Fig. 3 — Field map showing Big Mineral field with respect to Lake Texoma, Grayson County, Tex.

impractical because with unpredictable lake levels neither drilling nor producing operations could be conducted without frequent interruptions. Second, construct a drilling platform at the well site and service by boat or barge. Frequent periods of low water precluded the use of floating transportation as a dependable means of service. Third, drill directionally controlled wells from locations on high ground. This method was eliminated on the basis of economics and due to the fact that deflection angles required to reach shallow objective pays some 2,000 ft from the shore would be prohibitive.

Having determined the general method to be followed, it now became a problem for the mechanical and civil engineers to design the earthen platforms and roads. The first step was to determine the height to which the earth works should be built. From a study of lake level history, it was found that if the earthen platforms were built to an elevation of 620 ft above sea level, they would be above water about 92 per cent of the time. This appeared to be optimum since it would require doubling the average height of the platforms to obtain an additional 8 per cent accessibility.

Design features for a two-well earthen drilling platform and access roadway are presented in Fig. 6. This

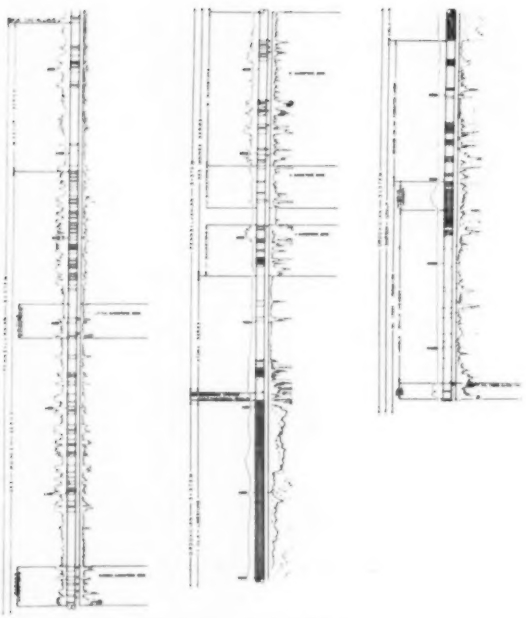


Fig. 4 — Type log, Big Mineral field.

platform is 175 ft wide and 190 ft long with the roadway being 28 ft wide at the top. Height of the platforms and roadways above the lake bed range from an average of 4 ft for shore line wells to a maximum of 10 ft in the deepest part of the Big Mineral arm.

The general construction method was to place and compact good quality clay and sandy clay material in 6-in layers to form the body of the structures. Fill material was obtained from borrow pits either in the lake bed, if it were dry, or from the shore in the event the work area was under water. Side slopes were then covered with a 6-in layer of filter bed material and topped with 14 in of large rip-rap rock to provide protection from rain run-off and wave action. The surfaces of the drilling platforms and roadways were covered with 6 in of crushed limestone.

Although the platform shown in Fig. 6 was designed for two wells, actual experience has shown that it will accommodate three. It was imperative that the platforms be constructed in advance of drilling in order that the development program would not be interrupted. The first nine were constructed as they were required. However, in September, 1953, at which time a one-year forecast of drilling was possible, a large scale single project involving the construction of 14 drilling platforms with roadways was undertaken. This proved to be an opportune time for construction since the lake level had receded to a point (elevation 602) which left the entire work area dry. In about 30 days some quarter million cubic yards of dirt had been moved and the fills completed. Fortunately, construction was completed prior to heavy rains in November which completely inundated the work area. The cost of this job could have been doubled had it been necessary to work in an inundated area.

As of June, 1954, 32 earthen drilling platforms and about 5 miles of access roadway had been constructed. There has been no interruption of the drilling program, either as the result of waiting on the completion of a platform or because of water inundation. On the cover of this magazine the aerial photograph taken in June, 1954, when the lake level was only 2 ft below the top of the platforms, reflects the magnitude of this project. At that time three wells were being drilled and some 32 wells already producing on earthen platforms.

Drilling Procedures

With a few exceptions drilling equipment and methods used in the Big Mineral field are similar to those employed in other fields in Texas. Two conditions not normally encountered in North Texas required special consideration by drilling engineers. The first of these problems, that of drilling wells in the lake bed area, was simplified by utilization of earthen drilling platforms and earthen access roadways. The only special provision necessary was to provide a means of disposing of well cuttings and waste mud since these materials could not be disposed of in the lake. Conventional steel pits for the mud circulation system were used with an additional tank provided for waste mud. Well cuttings and waste mud were either trucked from the well location or pumped from the drilling platform to a reserve pit on high ground.

The second problem was to devise means of improving drilling time in relatively hard shale and sand formations having dips ranging from 20 to 60 degrees. This problem was resolved after drilling only a few wells in the field. Shell's drilling engineers, together with the drilling contractors, conducted experiments on different drilling techniques, and it was finally determined that the best program to follow was to use oversize drill collars,[1,2] that is, either 7-in. in 7⅞-in hole or 7¾-in collars in 8¾-in hole in conjunction with jet bits. In addition, drilling time was improved by allowing hole deflection limits to be relaxed from three degrees for a 7,000-ft well to a graduated scale of one degree for each 1,000 ft of hole drilled. The use of these improved procedures resulted in a 45 per cent reduction in drilling time for a 7,000-ft well, as is demonstrated graphically in Fig. 7.

Low water loss, oil emulsion mud has been employed in drilling all wells. The use of this type of mud in

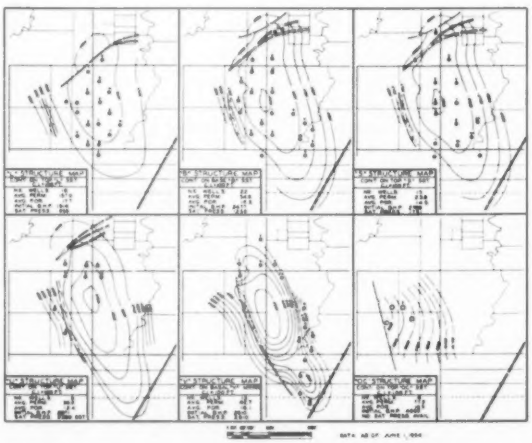
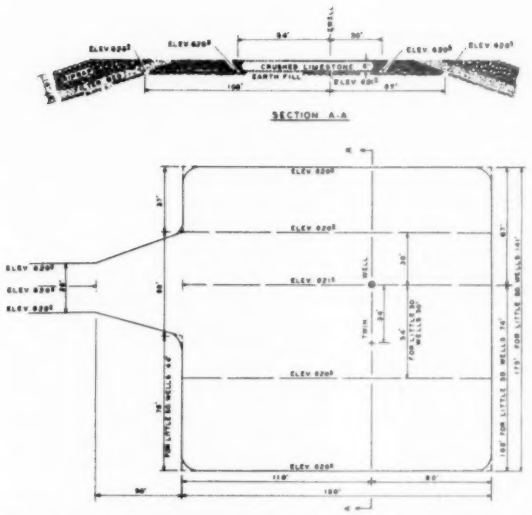


Fig. 5 — Structure maps and reservoir characteristics of six major productive zones in the Big Mineral field.


SECTION A-A
ELEV 820'
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ELEV 820'

on those producing from the shallow Little sandstone. A hydraulic bottom hole pump system has been chosen as the best method to artificially lift wells in the lake bed area. In contrast to conventional beam lifting, this method offers the advantage of freedom of operations during periods of high water and offers the opportunity for centralized control of the wells from a point on dry land.

Producing oil even by natural flow presents some problems when working in an area that is periodically under water. Even though wellheads of flowing wells are elevated, unforeseen conditions such as stormy weather and possibility of lake polution by flow line leaks offer problems in maintaining efficient production. Control equipment, therefore, has been installed so that the control of flowing wells could be accomplished at the header in the tank batteries. This system of controls includes a valve in the flow line at the tank battery and a diaphragm valve at the wellhead with a high-low pilot. The high portion of the pilot is used to control normal throttling of the well; whereas, the low portion of the pilot is used to shut in the well in case a flow line breaks in the lake bed.

It is a normal requirement by the Railroad Commission of Texas that separate tank batteries be installed for each producing horizon on the same lease. As may be seen, this would require as many as six separate batteries on some leases in the Big Mineral field. Early in the life of the field it was concluded that substantial savings could be realized if all oil from each lease could be commingled in common storage. An application was made and approved by the Railroad Commission to allow for commingling, provided stock tank oil from each horizon was metered. All of Shell's leases are now equipped with metering arrangements. The utilization of meters has made possible the most efficient use of lease tankage and operating personnel. Actual experience shows that the standard displacement type crude oil meters now in use operate well within the 2 per cent accuracy required by the Railroad Commission. Further efficiencies are obtained by use of automatic tank switching valves and ground level gauging. This equipment is helpful in the conservation of gravity by minimizing vapor losses. Metering facilities for obtaining individual well tests eliminate the need for separate test tanks.

Reservoir Performance

As mentioned previously, reservoir performance has been observed very carefully in each of the producing zones since the commencement of production. Although insufficient performance information was available to definitely establish a dominant source of energy available in each reservoir, certain logical assumptions were necessary in the early development stages to enable reservoir engineers to approximate the size of available oil reserves. It was assumed, therefore, that due to the relatively tight nature of the reservoir rock and the lack of well defined oil-water contracts in most of the reservoirs, that reservoir energy was probably furnished by gas expansion only. Volumetric studies of the extent of the reservoir rock, together with detailed quantitative electrical log analyses, a representative amount of core data, and PVT analyses of the available hydrocarbons, enabled the reservoir engineers to obtain sufficient information to estimate the magnitude of the oil accumulation and to design the exploitation program.

A very useful tool used by the reservoir engineer in determining the physical characteristics of each of the producing reservoirs has been the bottom hole pressure build-up curve. These data have been obtained on all Shell completions. Pressure data are obtained using an Amerada pressure gauge which is introduced into the well during stable flowing conditions. The well is then shut-in and the bottom build-up of pressure recorded for periods of from 24 to 48 hours. Pressure points are plotted as a logarithmic function of time. These data are used as a basis for calculating the average permeability of the reservoir rock, the absolute reservoir pressure in wells having slow build-up characteristics, and the efficiency of the well completion as measured by the "skin effect." [3]

To obtain an accurate performance history of each horizon, concerted efforts are being made to obtain accurate measurements of all gas and fluids produced from each of the reservoirs. Testing facilities are so arranged at tank batteries that individual well productivities of oil, gas, and water may be obtained monthly. Bottom hole pressure surveys are scheduled on a routine basis in order that an accurate pressure history of each horizon can be maintained.

With the accumulation of performance data, together with physical characteristics of the reservoir rock obtainable from core, electric log, and drill cuttings, it should be possible to forecast reservoir performance and determine what secondary recovery measures are applicable in increasing oil and gas recoveries. Admittedly, the cost of collecting these data is tremendous at the time. However, when taking into account the many technological advancements in reservoir control now being made and those which will be made in the near future, there is little doubt that the cost of obtaining good basic information on a reservoir shall be repaid many times.

Conclusion

As mentioned at the outset, the primary purpose of this paper is not to relate the history of the Big Mineral field. Its aim is to highlight the special problems involved in exploitation of this field and bring out the methods by which the various engineers solved these problems. It is quite evident that the engineering mission has been successfully accomplished. This was due primarily to the coordinated efforts of field engineers, subsurface geologists, reservoir engineers, mechanical engineers, and drilling engineers, all of whom have had important parts to play in the project. Although the engineers' contribution has been immeasurable, the operation could not have been a success had it not been accepted in an atmosphere of complete understanding and cooperation by the various operators, royalty owners, Railroad Commission, and other parties concerned.

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★★★

REPORT and INTERPRETATION

R. W. TAYLOR | EDITOR
JOURNAL OF PETROLEUM TECHNOLOGY

Permanent Literature of Petroleum Engineering

Another valuable addition to the permanent literature of petroleum engineering, as well as a working tool for immediate use, is now ready for distribution. It is *Volume 8* covering 1953 of the *Statistics of Oil and Gas Development and Production*, an annual publication of the Petroleum Branch, AIME.

Probably only those who buy the *Statistics* volume yearly realize that the publication date of this volume covering 1953 is much earlier than it has been in several years. This earlier availability of the volume will enhance its value, and it is the goal of the Petroleum Branch Production Review Committee to publish the next edition (covering 1954) even earlier.

Petroleum Branch Publications

The Petroleum Branch publishes several books each year that are valuable additions to the permanent literature of petroleum engineering, and they are offered to members at attractive discount prices. The photograph at the bottom of the page shows a bookcase in the Petroleum Branch office in Dallas which contains petroleum publications of the AIME assembled through the years. In 1954 the Branch published the aforementioned *Statistics* volume, the *Petroleum Transactions* volume, and an *Index to Petroleum Publications of the AIME*. By ordering these books, the approximately 1,000 new members who have joined the Petroleum Branch AIME in 1954, as well as older members, could make a good start on their library of permanent literature of the profession.

Questions often arise from new members as to the contents and value of these publications. Recently an inquiry was received by this office from a member who had noticed the *Transactions* order space on his AIME dues bill and did not know what was included in this volume. A description of each of the periodical publications of the Petroleum Branch follows.

Contents of the Volumes

The *Statistics Volume 8* contains both 1953 and cumulative data on virtually every hydrocarbon-producing reservoir in the world. It is considered throughout the industry as the most authoritative and comprehensive volume of its type published. An advertisement on page 44 of this issue gives further details on this volume.

The *Transactions Volume 201* covering 1954 will be published in early March of 1955. This bound volume contains all technical papers published in the JOURNAL OF PETROLEUM TECHNOLOGY during 1954.

Three papers not published in their entirety in PETROLEUM TECHNOLOGY because of space limitations will be printed in full in the 1954 volume. These papers are "Solution of the Equations of Unsteady-State, Two-Phase Flow in Oil Reservoirs," "The Mechanics of Formation Fracture Induction and Extension," and "A Method for Determination of Average Pressure in a Bounded Reservoir."

The *Index to Petroleum Transactions of the AIME*, which was published early in the fall, covered 32 years of Petroleum Transactions and other petroleum publications of the AIME. The Petroleum Branch plans to publish this type of index frequently in the future to make the use of the permanent literature much easier.

Books at Discount Prices

On page 44 of this issue is a list of books available to Petroleum Branch members at discount prices. To this list will be continually added the outstanding books on petroleum engineering as they are published. The discount prices offered on the volumes regularly published by the Petroleum Branch are: *Statistics*, $10 to non-members, $5 to members; *Transactions*, $7 to non-members, $3.50 to members when ordered in advance of publication; and *Index*, $5 to non-members, $3.50 to members.

One of the distinct advantages of AIME membership is the opportunity of obtaining a library of the permanent literature of petroleum engineering at a comparatively small cost. The officers and staff of the Petroleum Branch recommend that each member start his library immediately through the purchase of the volumes now available. ★★★

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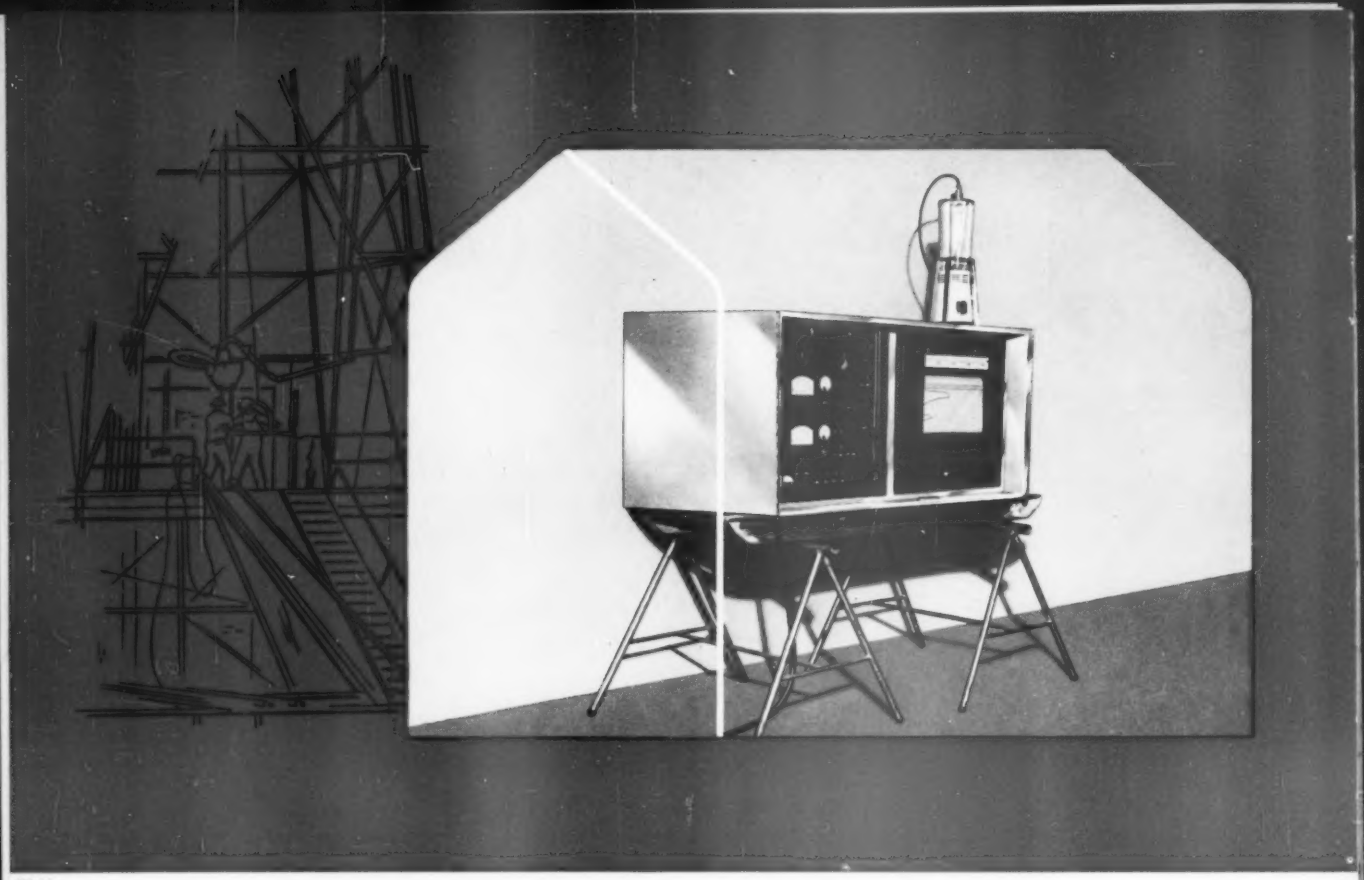

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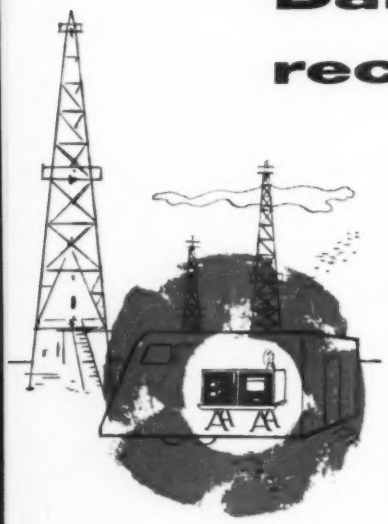

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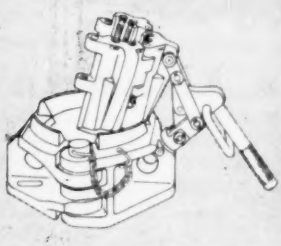

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PETROLEUM TRANSACTIONS

THE ROLE of BUBBLE FORMATION in OIL RECOVERY by SOLUTION GAS DRIVES in LIMESTONES

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ABSTRACT

Laboratory data show that the gas-oil ratio performance of non-uniform porosity limestones produced by solution gas drive is sensitive to producing rate and to fluid properties. Non-uniform porosity limestones are those for which laboratory solution and external gas drive tests yield considerably different relative permeability ratio characteristics.

The oil recovery performance by solution gas drive depends directly on the number of gas bubbles formed. Laboratory rates of pressure decline, which are 100 to 10,000 times greater than normal field rates, cause the formation of an unusually large number of gas bubbles. This results in abnormally high oil recovery efficiencies. Since it is impractical to reproduce the number of bubbles formed under field conditions, laboratory solution gas drive data on non-uniform porosity limestones are therefore not directly applicable to field operations. However, certain laboratory data can be used to make a conservative estimate of field performance.

The concepts presented in this paper indicate the possibility that increased field oil recoveries may be obtained from non-uniform porosity limestones by rapidly reducing reservoir pressure for a short interval of time. It has yet to be established that significant improvements in oil recovery from such reservoirs can be realized by varying the pressure decline rate within limits possible in the field. However, the possibility that recovery may be increased in this manner warrants further study.

Manuscript received in Petroleum Branch office on Sept. 8, 1954. Paper presented at Petroleum Branch Fall Meeting in San Antonio, Oct. 17-20, 1954.

INTRODUCTION

Limestone reservoir rocks can be divided into two general classes according to the nature of their pore space. One class has a comparatively uniform pore system composed mainly of voids between grains of the rock (intergranular type porosity). The other class, in addition to having intergranular porosity, has a secondary pore system composed of combinations of solution cavities, fractures, etc., and is considered to have non-uniform porosity.

It has been shown in a previous publication[1] that the laboratory measured gas-oil flow behavior of uniform type porosity limestones is essentially the same for a test simulating a field solution gas drive as for one simulating an external gas drive. For non-uniform porosity type limestones a significant difference in gas-oil flow behavior was found. More efficient behavior was

[1]References given at end of paper.

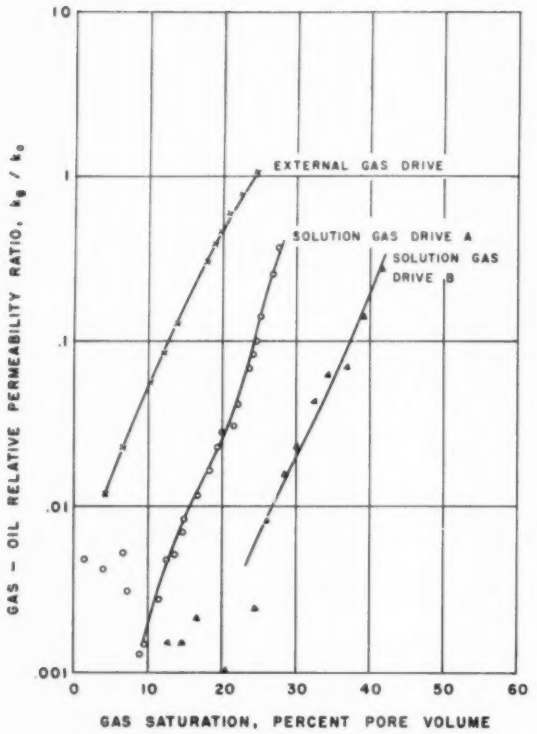

FIG. 1—RELATIVE PERMEABILITY CHARACTERISTICS OF WEST TEXAS REEF LIMESTONE CORE.

Permeability = 21 md.; Porosity = 20 per cent.
Curve A: Methane and C_{10}-C_{12}, bubble point pressure = 200 psig.
Curve B: Nitrogen and C_{10}-C_{12}, bubble point pressure = 1,000 psig.

observed during a solution gas drive test. This difference in oil displacement behavior was attributed to the complex nature of the pore space and to the fact that the source of gas in the two displacement operations is not the same. That is, in a solution gas drive the gas is evolved from oil within the pores of the rock itself, while in an external drive the gas is injected from an outside source.

Experimental work beyond that previously published shows that the laboratory solution gas drive behavior of non-uniform porosity limestones is not unique. Differences in oil recovery up to twofold, at the same flowing gas-oil ratio, were found by varying the test conditions. A variation in results on uniform porosity type rocks was also observed. However, the variation in flow behavior of one core under different test conditions was small and of the same magnitude as the observed differences between results of identical tests on separate cores of the same rock material.

For the non-uniform porosity limestones, the laboratory solution gas drive relative permeability characteristics were found to be affected by: (1) rate of pressure decline, (2) original bubble point pressure of the gas-oil solution, (3) oil viscosity, and (4) gas solubility characteristics.

Two examples of the variation observed on non-uniform porosity limestones are shown in Figs. 1 and 2. The data in Fig. 1 were measured on a West Texas reef sample and those in Fig. 2 on a Mid-Continent limestone sample. The data for test B in each figure were obtained using a gas-oil solution having an initial bubble point pressure of 1,000 psi. The initial bubble point pressure for tests A was 200 psi. In addition, the pressure decline rates for tests B were faster than for tests A.

The data of Figs. 1 and 2 are quite typical of those obtained on non-uniform porosity limestones, and no satisfactory explanation has been heretofore published. The purpose of the studies reported in this paper was therefore: (1) to determine the reason for the observed variation in results of laboratory solution gas drive tests; (2) to design a laboratory test which would provide data for predicting field performance; and (3) to determine if special production practices in certain oil fields could result in improvements in oil recovery. The answer to the first question has been obtained. These studies offer only an insight into the possible means for answering the second and third questions.

FORMATION OF GAS SATURATION IN POROUS MEDIA

During all laboratory solution gas drive tests it has been observed that the oil is in a supersaturated state.[1] That is, the oil contains more dissolved gas than would be predicted from PVT relationships. In terms of pressure, the degree of supersaturation is expressed as the difference between the bubble point pressure of the oil and the actual pressure. Some degree of supersaturation is always observed to exist throughout the entire pressure depletion life of solution gas drive tests. It is noted, in fact, that the supersaturation history of a test actually is closely related to the measured flow behavior. In general, the higher the degree of supersaturation, the greater is the displacement efficiency of oil by gas.

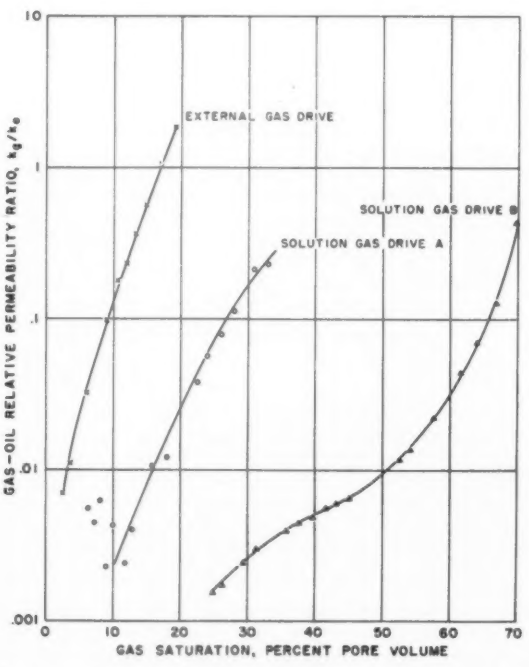

FIG. 2—RELATIVE PERMEABILITY CHARACTERISTICS OF MID-CONTINENT LIMESTONE CORE.

Permeability = 1 md.; Porosity = 30 per cent.
Curve A: Methane and C_{10}-C_{12}, bubble point pressure = 200 psig.
Curve B: Methane and C_{10}-C_{12}, bubble point pressure = 1,000 psig.

By experience, it is known that supersaturation results in the formation of bubbles in a gas-oil solution. One might conclude, therefore, that the manner in which bubbles form and subsequently grow controls the displacement of oil during any solution gas drive. Since not all rocks exhibit unusual laboratory solution gas drive performance, the pore geometry probably also plays an important role.

A study of results such as are presented by Figs. 1 and 2, and visual studies of non-uniform porosity limestones indicate that only a part of the total gas saturation is responsible for the observed gas-oil ratio performance. This implies that part of the porosity of these non-uniform rocks does not contribute to gas permeability. Nevertheless, if the saturation existing only in the conductive regions could be correlated with the flowing gas-oil ratios, it is believed that the differences exhibited in solution drive behavior would be resolved into one basic flow relationship. At present no way of obtaining such a correlation is apparent for naturally occurring rocks.

The above considerations indicate the influence of (a) the formation of gas bubbles, and (b) the displacement of oil by expanding gas bubbles on depletion characteristics of non-uniform porosity rocks.

Formation of Gas Bubbles

Kennedy and Olson[2] have shown that the rate at which gas bubbles form in a gas-oil solution is a function of the supersaturation. This in turn depends on the rate of pressure reduction. The higher the supersaturation, the greater is the rate at which gas bubbles form. Since in laboratory solution gas drive tests the supersaturation histories were different, it was logical to conclude that the oil displacement behavior was affected by the rate of bubble formation, and hence by the number of gas bubbles formed.

Information in the literature[2,4,5], together with data obtained at the Stanolind Research Center on gas bubble formation, were used to predict the total number of bubbles which might form under various rates of pressure decline. Although the details of this study are beyond the scope of this paper and will be covered in a future publication[6], an example of the results can be shown here. The predictions were made using different assumptions than were made by Kennedy and Olson[2]. Nevertheless, the agreement with their predictions on the number of bubbles formed is satisfactory, considering that both methods give only order of magnitude values.

The theoretical supersaturation history as well as the cumulative number of bubbles formed are shown in Fig. 3 for a gas-oil solution undergoing constant rates of pressure decline of 1,000, 100, 10, 1, and 0.1 psi per day. These rates of pressure decline cover the range of importance in field and laboratory solution gas drives. It must be emphasized that the results of Fig. 3 apply only to a specific system. However, the effect of rate of pressure decline on the number of bubbles formed is the same for all systems; namely, an increase in the rate of pressure decline by a factor of 10 results in about 10 times as many bubbles being formed.

The significant information shown in Fig. 3 is that the higher the rate of pressure decline, the greater is the total number of bubbles formed in a system. Also, essentially all of the bubbles are formed throughout a relatively short time interval during the pressure depletion life. From Fig. 3 it can be estimated that in usual laboratory tests the number of bubbles formed is 100 to 10,000 times greater than the number formed under normal field conditions.

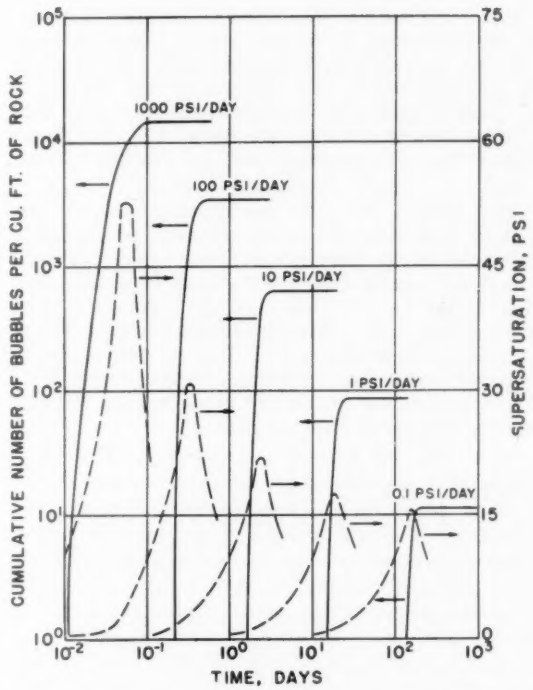

FIG. 3 — CALCULATED SUPERSATURATION AND BUBBLE FORMATION HISTORY WITH VARYING RATES OF PRESSURE DECLINE.

Values shown apply to a hypothetical system; however, the relative values apply to any system, e.g., a 10-fold increase in rate of pressure decline results in a 10-fold increase in the number of bubbles formed.

Displacement of Oil by Expanding Gas Bubbles

It is reasoned that the number of gas bubbles formed during the pressure depletion of a gas-oil solution in a porous material will have an effect on the oil displacement behavior. In this type of recovery method, oil is pushed out of a pore by the evolution of a gas bubble within this pore or by the intrusion of gas from another pore.

A gas bubble grows in two ways; namely, by the addition of gas which diffuses from adjacent oil and by expansion due to pressure reduction. As it grows it will invade the network of pores which offers the least resistance. This bubble will unite with others, eventually forming a continuous gas phase which extends to the exit of the porous body. After this occurs, gas flowing in this connected network of pores will be less effective in displacing oil from other pores. However, isolated gas bubbles will still be present, and will continue to displace oil with the maximum efficiency until they join the continuous gas phase. The more bubbles present, the greater will be the displacement of oil from regions not invaded by the conductive gas saturation. Figs. 1 and 2 provide examples showing the

effect of the number of bubbles on recovery. The approximate number of bubbles formed in each of these tests has been calculated using methods referred to in the previous section. The calculations show that about 10 times as many bubbles were formed in the B tests as were formed in the A tests reported in each of the figures. This is in agreement with the concepts outlined above.

The amount by which bubble formation and the growth of bubbles affects flow behavior in a solution gas drive on uniform porosity type rocks has been found to be small, except in the early stages of depletion. In this type of rock all of the pores act as fluid conductors as well as fluid storage spaces. Displacement of oil from a specific pore or from a group of pores does not require the formation of a gas bubble in it. The reason is that gas evolved upstream can enter and thereby displace oil from any pore.

This is not the situation in non-uniform porous materials as is suggested above. In these, some pores act as fluid conductors as well as storage spaces while others are essentially storage spaces. In other words, comparison of the oil recovery performances calculated from laboratory solution and external gas drives indicates the presence of pore space which is not entered by an immiscible, non-wetting, displacing fluid (such as gas) during an external drive. These pores, or clusters of pores, have capillary pressure-saturation characteristics which are different from the "conductor" pores comprising the rest of the pore space. Recovery of oil from these "storage" pores by an external gas drive can be accomplished only at high gas-oil ratios. However, in this type of pore, or cluster of pores, the formation of a gas bubble during a solution gas drive can result in the displacement and recovery of this oil when the system is producing at a relatively low gas-oil ratio.

The above discussion explains why a laboratory solution drive recovers more oil than does an external gas drive at comparable flowing gas-oil ratios. It also offers an explanation for the variations in oil recovery observed in solution gas drives. To summarize, recovery of oil from these storage pores can only result from the formation of bubbles therein. If the number of bubbles formed during a solution drive varies, the recovery of oil from these pores will vary also. Where the volume of these pores comprises a high percentage of the total volume of the rock, these variations will be significant.

It was shown previously that at field rates of pressure decline the number of gas bubbles formed is small compared to the number formed in laboratory tests. This can be taken qualitatively to mean that laboratory solution gas drive tests will yield a higher oil displacement efficiency from a non-uniform limestone rock than should be expected in the field.

To confirm further the ideas expressed above, several solution drive tests were conducted under special conditions. The following section describes apparatus and general experimental techniques used in these tests. A description of the special test conditions employed is given in a later section, together with a discussion of the objectives of the experiments and of the results obtained.

DESCRIPTION OF APPARATUS AND PROCEDURE

The core samples used in this work were selected from producing sections in oil reservoirs and also from outcrop formations. All samples were cylindrical in shape and ranged from 2½ to 4½ in. in diameter. These samples varied from 6 to 11 in. in length with one exception. This exception was a specially prepared 6 ft long core. The apparatus and technique of mounting and testing these samples from 6 to 11 in. long have been described in a previous publication.[1]

The 6 ft long core sample was prepared from a piece of Cordova shellstone which outcrops near Austin, Tex. This core sample had a uniform diameter of 4½ in. for 5 ft of length. The diameter was then reduced uniformly over a 3 in. long section, and the remaining 9 in. of the core were shaped into a square cross section, 1 in. on a side. The core was prepared in this manner to minimize effects of boundary conditions on flow test results. In the flow tests this reduced section formed the downstream end of the core. At a point 1 ft from the downstream end of the core a small diameter tube was attached for pressure measurement. Fluid gathering plates were attached to each end of the rock and the assembly was surrounded by a thermosetting plastic. The plastic-sealed core was then placed in a steel cell, and the space between the inside of the cell and the outside of the core was pressured to 400 psi.

The technique of saturating the 6 ft long Cordova shellstone core differed from that used on the smaller samples. The large core was first saturated with a gas-free relatively pure hydrocarbon in the range of C_{10}-C_{12}. Next, methane gas was injected and oil produced until the average gas saturation reached approximately 30 per cent pore space. The injection pressures were very close to the bubble point pressure of the methane-C_{10}-C_{12} solution to be used in the flow tests. After flow was terminated, methane gas was injected into the core through a regulator set to operate at the intended bubble point pressure. After various intervals of time the core was shut off from the methane supply, and the gas phase pressure change with time was observed. When the gas phase pressure drop became negligible for an interval of several hours, the residual oil was considered to be substantially at equilibrium with the gas present.

The gas phase was then removed by the injection of 200 psi bubble point oil, first at an injection pressure slightly above the bubble point pressure, then later at an injection pressure of 300 psi. The extent of liquid saturation was determined by both material balance and fluid compressibility checks. It was found that 2 pore volumes of oil were sufficient to remove the gas and thus completely saturate the core.

In addition to the previously described apparatus[1], a special constant rate pump was used in the tests where a constant rate of pressure decrease or increase was used. This pump was powered by a constant speed electric motor working through a machine lathe gear train. The pump was connected to a back pressure regulator. Depending on the manner of connecting the pump, the pressure could be either increased or decreased at a constant rate.

RESULTS AND DISCUSSION

Short Core Tests

The usual laboratory solution gas drive test involves a pressure depletion time of hours compared with years for an actual reservoir. The laboratory pressure decline rates are accordingly orders of magnitude greater than field rates. Under such conditions the number of gas bubbles formed in a laboratory test is likewise much greater than the number formed in the reservoir.

The most direct method for reducing the number of bubbles formed during laboratory tests is to use slower rates of depletion. However, it is impractical from the standpoint of time alone to perform laboratory tests at field rates. There is also another serious objection to reducing laboratory depletion rates. A decrease in the rate of pressure decline also means a decrease in the pressure drop across the system and an increase in the "end effect," or liquid pile-up at the downstream end of the core. If this end effect is appreciable, it becomes impossible to obtain reliable gas-oil relative permeability data. These two factors militate against the direct laboratory measurement of correct solution drive gas-oil relative permeability characteristics. Nevertheless, laboratory tests described in the following paragraphs have been made to show the effect of bubble formation on oil recovery efficiency. These tests actually allowed measurement of the amount of oil produced solely as a result of the formation and growth of gas bubbles in the storage pores of a non-uniform porosity limestone sample.

Two nearly identical tests were performed on a single reservoir sample. The main feature of each test was the execution of a solution gas drive after the initial establishment of a high gas saturation (the necessity for the gas saturation will be explained later). The two solution gas drives were performed at greatly different rates, so that in one test few, if any, bubbles would be formed, whereas in the other test, many bubbles would be formed.

In order to form essentially no bubbles during a depletion test, it is sufficient to maintain supersaturation at a low value, such as 15 psi or less. The amount of supersaturation which will exist in a core subjected to a given rate of pressure decline depends, of course, on how fast the dissolved gas can diffuse out into the connected gas phase. Since it was desired to use reasonable rates of pressure decline in the tests, it was therefore necessary first to establish a high gas saturation prior to the solution gas drive.

Fig. 4 is an example of results of diffusion tests on a sample of non-uniform porosity limestone. Although these data were not actually obtained on the Reef sample, they serve as an excellent example of the characteristics of such rocks. As can be seen from Fig. 4, at high gas saturations the maximum rate of pressure decline which can be maintained without exceeding a given degree of supersaturation increases rapidly with increasing gas saturation. A solution gas drive in which no bubbles are formed cannot, therefore, be carried out at reasonable laboratory rates unless a high gas saturation is first established.

A further reason for initially driving the cores to a high gas saturation was to insure that any oil produced during the subsequent depletion test could come only from pores not normally emptied during an external gas drive, i.e., from the storage pores. Actually, the

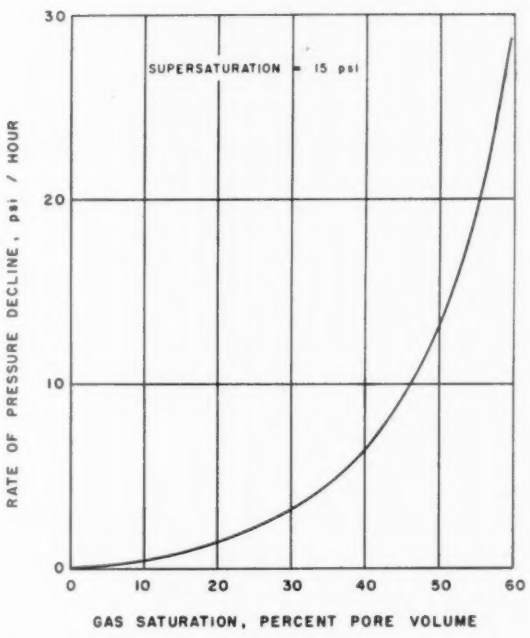

FIG. 4 — RELATIONSHIP BETWEEN PRESSURE DECLINE RATE AND GAS SATURATION WITHOUT BUBBLE FORMATION FOR CORDOVA SHELLSTONE.

Methane and C_{10}-C_{12}.

solution drives were also followed by final external gas drives to recover any newly released oil which might have been held back by end effect during the depletion process.

The two nearly identical experiments were performed on a single sample of the previously mentioned Reef limestone. In each of the two tests, the sample was saturated with gas-free C_{10}-C_{12}. Following this, the initial external gas drive was applied with a pressure differential sufficiently high to overcome end effect. This drive was terminated at 57 per cent pore space average gas saturation. After establishing the gas saturation, the core was pressured to 1,000 psig with gas until the residual oil was substantially at equilibrium at this pressure. At this point the core was depressured at a controlled rate of pressure decline. At the end of the pressure depletion a final external gas drive was applied at the same pressure conditions as were used for the initial external drive.

The two series of experiments were identical except for the rate of pressure decline during the depletion process. The two rates used during the solution drives were 38 and 2,100 psi per hour. The 38 psi per hour rate was chosen on the basis of a calculation which indicated that the degree of supersaturation attained at this rate would not exceed 15 psi, and thus no bubbles would form. The 2,100 psi per hour rate was the maximum rate attainable. A special bubble formation calculation indicated that even at the existing high gas saturation (57 per cent), many bubbles would be formed at this rate of pressure decline.

The results of these tests are given in Fig. 5. The data are presented as the flowing gas-oil ratio for the external drives versus the oil recovery as per cent pore

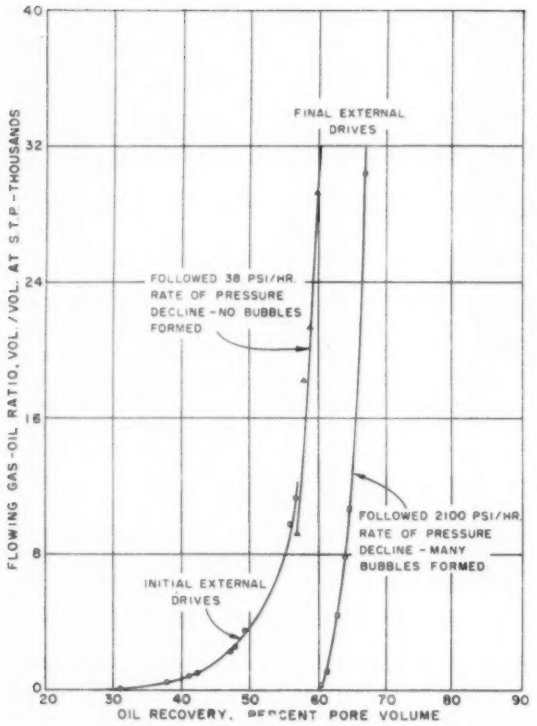
FLOWING GAS-OIL RATIO, VOL./VOL. AT S.T.P.-THOUSANDS
OIL RECOVERY, PERCENT PORE VOLUME
FINAL EXTERNAL DRIVES
FOLLOWED 38 PSI/HR. RATE OF PRESSURE DECLINE - NO BUBBLES FORMED
FOLLOWED 2100 PSI/HR. RATE OF PRESSURE DECLINE - MANY BUBBLES FORMED
INITIAL EXTERNAL DRIVES

FIG. 5 — FLOWING GAS-OIL RATIO PERFORMANCE FOR REEF LIMESTONE CORE.

Permeability = 21 mds; Porosity = 20 per cent.

space. The effect of bubble formation on oil recovery for this non-uniform porosity limestone sample can be measured by comparing the performance of the two final external gas drives. The shift to the right for the gas drive which followed the rapid rate of pressure decline shows the increase in oil recovery due to bubble formation. This increase is appreciable in spite of the initial high gas saturation. The gas drive following the slow rate of pressure decline shows no significant increase in oil recovery. Identical tests on a sandstone core sample (uniform porosity) showed no effect of bubble formation on oil recovery.

The significant difference between the limestone core tests, therefore, is the increased oil recovery resulting from the formation of a large number of bubbles during the 2,100 psi per hour pressure decline solution gas drive. *For the other case, where very few bubbles were formed, the performance is a continuation of the normal external gas drive behavior.* On the basis of the above results, there is reason to believe that similar behavior should be observed at lower gas saturations. This would mean that in the field, where a small number of bubbles are formed, the oil recovery performance under a solution gas drive might approach that predicted from the flow characteristics measured in the laboratory by an external gas drive.

LONG CORE TESTS

The preceding tests substantiate the theory concerning the role of bubble formation on the recovery of oil from non-uniform porosity limestones. However, a field begins its producing history with no gas saturation, and the previous tests began with a connected gas saturation initially much greater even than the final gas saturation in a depleted reservoir. This difference is believed to be irrelevant with respect to the conclusions already reached. On the other hand, the actual establishment of the initial flowing gas saturation in a reservoir is a complex process. To bridge this gap between field conditions and the tests described to this point, experiments have been made in which no initial gas saturation was present, and in which bubble formation rates approached those for reservoir conditions.

The first consideration in selecting the operating conditions for such a test was to decide on the minimum practical rate of pressure decline. Obviously, a rate of 0.1 to 1 psi per day was unsatisfactory from the time standpoint alone. A decline rate of 10 psi per day was selected. This value was not considered too high, and it probably represents the maximum rate under which a reservoir might be produced even for a short interval of time.

The selection of a 10 psi per day rate of pressure decline presented a real problem with regard to end effect. At such a low rate of decline the pressure drop across a core is usually negligible, and end effect renders gas-oil relative permeability data meaningless. However, by a special core design this difficulty could be obviated. By increasing the flow resistance of the system, it was possible to operate at higher differential pressures with the same rate of pressure decline. The increase in the flow resistance of the system was accomplished in two ways. First a practical maximum length of core was used; namely, 6 ft. Secondly, addi-

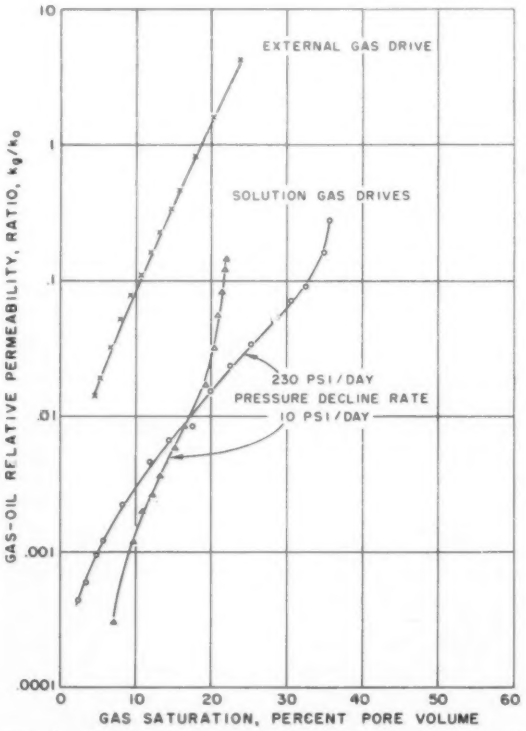

FIG. 6—RELATIVE PERMEABILITY CHARACTERISTICS OF CORDOVA SHELLSTONE.

Permeability = 200 mds; Porosity = 25 per cent.
Solution gas drives used a 200 psig bubble point solution of methane and C_{10}-C_{12}.

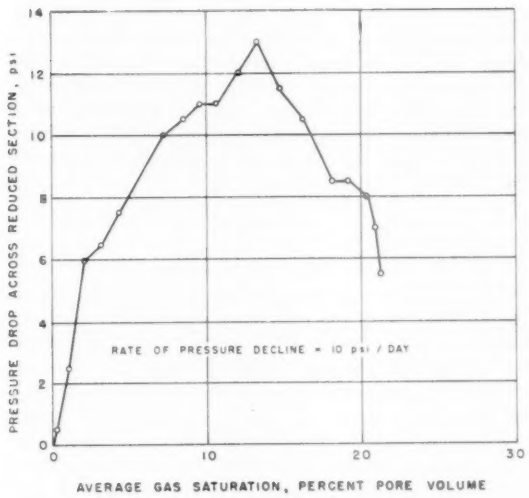
PRESSURE DROP ACROSS REDUCED SECTION, psi
RATE OF PRESSURE DECLINE = 10 psi / DAY
AVERAGE GAS SATURATION, PERCENT PORE VOLUME

FIG. 7 — PRESSURE DROP PERFORMANCE ACROSS REDUCED SECTION OF CORDOVA SHELLSTONE.

tional resistance without a change in important capillary characteristics was obtained by reducing the cross-sectional area of the downstream end of the core. Because it was impractical to obtain an oil field core of the desired size, an outcrop (Cordova shellstone), was selected for these tests. The manner in which the core was shaped has already been described.

An external gas drive and two solution gas drives at widely different rates of pressure decline were performed on this large core sample. The results of these tests are presented by Figs. 6 through 8. Fig. 6 shows for these three tests the relationship between the gas-oil relative permeability ratio, k_g/k_o, and the gas saturation in per cent pore space. The divergence noted between the laboratory external and solution gas drives indicates that this rock has a non-uniform porosity.

The rates of pressure decline for the two solution gas drive runs were 10 psi per day and 230 psi per day. The reliability of the k_g/k_o data from the standpoint of end effect can be evaluated from the history of the pressure drop across the reduced section of the core and from gas-oil capillary pressure data. Capillary pressure characteristics indicated that end effect would be negligible as long as the pressure drop across the reduced section exceeded 1 psi. Fig. 7 presents the pressure drop history for the 10 psi per day run and shows that the test was not detrimentally influenced by end effect. The amount of end effect was, of course, even less with the fast decline rate.

The results of the two individual solution gas drive tests show a difference in recovery efficiency. At pressure depletion, the 10 psi per day decline rate test resulted in an oil recovery of 22 per cent pore space. This may be contrasted with the 36 per cent recovery achieved in the test carried out at the higher rate. This 64 per cent increase in oil recovery is attributed to an increase in the number of bubbles formed during the faster run.

Fig. 8 shows the wide variation in supersaturation which existed for the two individual solution gas drive tests. A calculation of the number of bubbles formed indicates that at the fast rate of pressure decline there were about 100 times more bubbles than at the slower rate. The effect which this increased number of bubbles had on the efficiency of oil recovery was not apparent until an average gas saturation of approximately 17 per cent pore space was reached. Beyond this saturation the difference in oil displacement efficiency for the two tests increased as depicted by the position of the separate k_g/k_o curves.

The increased number of bubbles formed during the rapid decline test does not explain the relative positions of the two solution drive curves of Fig. 6 in the range from 0 to 17 per cent gas saturation. Their relative positions can, however, be explained by visualizing the variation in extent of the connected gas saturation as a function of time. Since the pressure is always lowest at the downstream end of the core, the gas phase develops to a greater extent and becomes connected first in this part of the system. The connected portion of the gas phase then progresses upstream. This will result in the measurement of higher k_g/k_o values at a given average gas saturation than would exist if the connected portion of the gas phase was distributed uniformly throughout the core. This is also evident, at low gas saturations, in Figs. 1 and 2.

The differences in the depletion rates and the measured pressure drops across the system for the two runs of Fig. 6 show that the above explanation is probably correct. For the test carried out with a pressure decline rate equal to 10 psi per day there was no measurable pressure drop (0.5 psi could have been detected) across

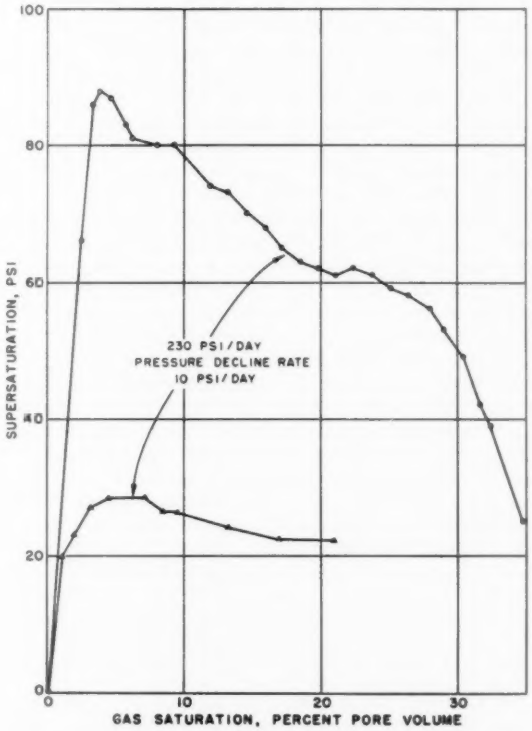

FIG. 8 — LABORATORY SUPERSATURATION PERFORMANCE OF CORDOVA SHELLSTONE.

Initial bubble point pressure in each test was 200 psig using a solution of methane and C_{10}-C_{12}.

the 4½ in. diameter section, and a maximum pressure drop across the reduced section of 12 psi. For the fast rate of pressure decline the pressure drops were 4 to 6 psi and 200 psi, respectively. This indicates a definite possibility of progressive gas phase development during the fast pressure decline test. If the rate of progression of conductive gas saturation had been the same in the two tests, it can be reasoned that the measured relative permeability curve for the faster test would be to the right of the curve for the slower test throughout the entire range of gas saturation.

Significance of Study in Regard To Reservoir Performance

One objective of this study was to design a laboratory test which would give results applicable to the prediction of field solution gas drive performance. Fig. 3 shows that the number of bubbles formed under field rates of pressure decline (0.1 to 1 psi per day) would be less than 100 bubbles per cubic foot of reservoir rock. The exact number of bubbles would depend upon the rock and the fluids involved. Nevertheless, the value is an order of magnitude less than the number of bubbles calculated to have been formed in the 10 psi per day test discussed above.

On this basis it may be concluded that the results obtained from the above test do not represent normal field solution gas drive performance. It may be concluded from the above tests, however, that a decrease in the rate of pressure decline (at least throughout the range investigated in the laboratory) results in a lower efficiency of oil displacement from non-uniform porosity limestones. It may be proposed again that a limiting value on reservoir performance would be that predicted by the laboratory external k_e/k_o relationship, with the possibility that the field solution drive behavior would be somewhat more efficient. At least, the use of the external gas drive characteristics should give a conservative estimate of reservoir solution drive behavior.

In laboratory solution gas drives on non-uniform porosity limestones, oil recovery efficiency is seen to be improved appreciably by increasing rates of pressure decline. In the field the usual rates of pressure decline are 100 to 10,000 times slower than are practical in the laboratory. It has yet to be established that significant differences in oil recoveries from non-uniform porosity limestone reservoirs can be realized by varying the pressure decline rate within this lower range.

However, we cannot discount the possibility that unconventional production practices might be devised to yield recoveries approaching those obtainable in the laboratory. To achieve this goal would require a pressure decline rate of at least several psi per day. Nevertheless, it is possible that such a rate would need to be maintained for only a few days. The reason is that at any particular rate of pressure decline, the majority of bubbles are formed in a short time. For example, at about 10 psi per day pressure decline rate nearly all the gas bubbles are formed within three days. Of course, the most suitable time to subject the reservoir to such a fast decline rate would be when the reservoir pressure is near the bubble point. At this stage of depletion the gas-oil ratio is low, permitting maximum liquid withdrawal rates. Since the productivity of the wells would control pressure decline, the use of deep penetrating fractures would probably be indicated. Although these latter conclusions must, at present, be classed as speculative, their significance is great enough to demand further study.

CONCLUSIONS

1. The laboratory solution gas drive oil recovery efficiency of non-uniform porosity limestones increases with an increase in the number of gas bubbles formed. Pressure decline rate is the important factor in establishing the number of gas bubbles formed.

2. No practical test is available to measure in the laboratory the solution gas drive oil recovery performance at field rates of pressure decline. It is postulated that laboratory external gas drive data can be used to make a conservative prediction of field solution gas drive performance for non-uniform porosity limestone reservoirs.

3. The concepts presented in this paper indicate the possibility that increased field oil recoveries may be obtained from non-uniform porosity limestones by rapidly reducing reservoir pressure for a short interval of time. It has yet to be established that significant improvements in oil recovery from such reservoirs can be realized by varying the pressure decline rate within limits possible in the field. However, the possibility that recovery may be increased in this manner warrants further study.

ACKNOWLEDGMENT

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A NEW TOOL for PERFORATING CASING below TUBING

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ABSTRACT

The continued use of permanent-type well completion has pointed up the need for more powerful through-tubing perforating equipment. A new expendable shaped charge perforator has been developed in which the charges are run through the tubing in a vertical position and then opened out to a horizontal position when at the desired shooting zone. The performance of this new tool is comparable to that of conventional casing type perforators.

This paper describes the new tool and its applications. Performance data in targets and under various actual well conditions are presented.

INTRODUCTION

The general acceptance and increasing use of permanent-type well completion by the oil industry has indicated the need for through-tubing perforating equipment with performance comparable to that of conventional casing type perforators.[1,2] To achieve the performance desired, a new, expendable, shaped charge perforator has been developed with adequate power for effectively perforating both 5½-in. and 7-in. casing below tubing. This has been accomplished without resulting severe damage to the casing and can be obtained under extremes of pressure and temperature. The design of this new tool is a radical departure from previous concepts of tubing guns since it was felt that the two major limitations imposed by previous designs severely handicapped performance.

The first of these limitations was the restriction imposed upon the length of the charges by the necessary small inside diameter of the carrier. This resulted from the necessity for compromises in designing a hermetically sealed gun small enough to allow free passage through 2-in. tubing, yet with sufficient wall thickness to withstand some minimum pressure. In an effort to overcome this limitation, the charges were in some cases placed at an angle with the axis of the well with resulting loss in effective depth of penetration.

The second limitation concerned the extreme distance of the charges from the casing when the gun was fired. An example of the latter situation is demonstrated by the fact that a conventional 1¾-in. tubing gun centralized in 5½-in., 17-lb casing has a clearance of more than 1-9/16-in. on all sides. This means that a considerable portion of the force from each charge must be expended in penetrating this 1-9/16-in. of well fluid before it even reaches the casing. With the gun centered in 7-in., 23-lb casing, the amount of fluid penetration required of each jet is in excess of 2¼-in. In a situation where the 1¾-in. gun is touching one side of the 5½-in., 17-lb casing, the jets from the charges on the opposite side have more than 3⅛-in. of fluid to penetrate. A similar situation in 7-in., 23-lb casing necessitates the penetration of more than 4-9/16-in. of fluid. The penetrating effect of the charges is severely impaired in passing through so much fluid. Under such conditions, there is usually insufficient force left to penetrate the casing. Previous studies have shown the decided disadvantage of having to shoot through such an excessive quantity of well fluid.[4,5] The problem, then, was how to position large powerful charges close to the casing prior to firing and still manage free passage through 2-in. tubing.

The solution appeared to be in some method of folding sealed charge units in an open type, expendable, 1¾-in. carrier for travel through the tubing, and unfolding them upon their arrival at the shooting zone in the casing. It was desired to control the mechanism electrically from the surface through the regular shooting cable, making the release of the charges independent of the physical characteristics of the well, yet with a provision to prevent the gun from firing until the

[1]References given at end of paper.

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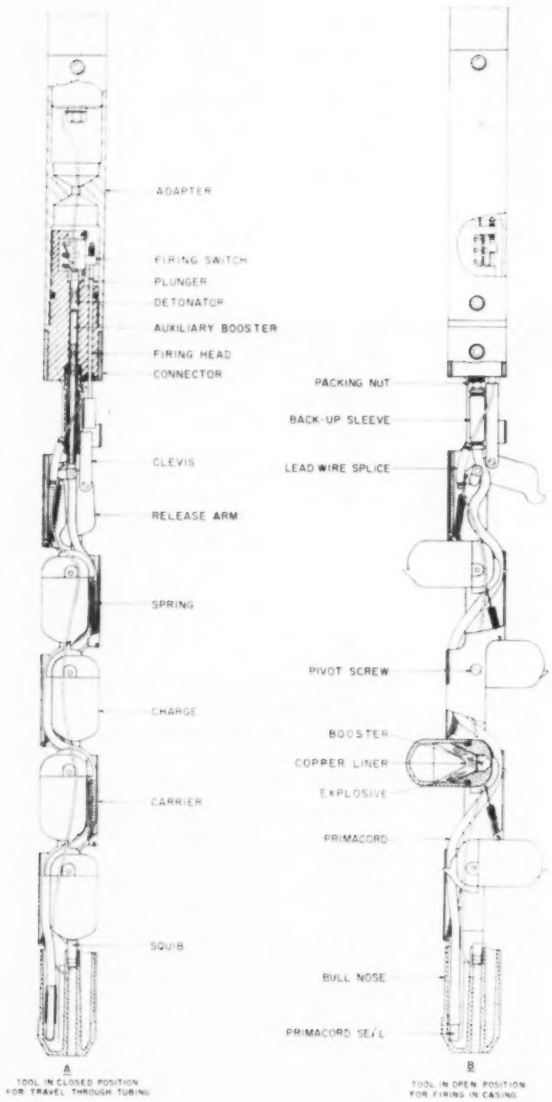

FIG. 1—TUBING GUN IN CLOSED AND OPEN POSITIONS.

charges were in the proper firing position. Also, with the charges in the open firing position, it must be possible to reposition them and return the gun to the surface through the tubing, without damage to the tubing, should this be desired.

It was felt that any new design should extend the use of the gun over as great a scope of well conditions as possible; therefore, it was decided to design all components to operate at pressures of 10,000 psi and temperatures of 300° F.

This new gun travels through the tubing with the charges locked in a vertical position as shown at A in Fig. 1. When in position in the casing below the tubing, the charges are released at the will of the operator to a horizontal firing position as shown at B in Fig. 1. This innovation of swinging charges provides several distinct advantages, namely:

1. The design of the charge is not restricted by the inside diameter of the gun case, therefore a larger and more powerful charge is possible.

2. Since it is not necessary to angle the charges from the horizontal (unless desired) greater effective depth of penetration is achieved.

3. The spring loaded charges snap open and tend to center the gun in the casing thus distributing the clearance space more equally between the charges on each side of the gun.

4. Since the off-center pivoted charges open from a 1¾-in. diameter to a horizontal position at 180° phasing, resulting in a maximum effective opened diameter of 4⅜-in., they are much closer to the casing, thus minimizing the fluid through which each jet must pass, resulting in larger holes and deeper penetration.

DESCRIPTION OF NEW TUBING GUN

This tubing gun consists of three fundamental components; namely, carrier assembly, bottom release, and safety firing head.

A carrier, charges and connector make up the carrier assembly. The carrier, a brittle, thin wall, 1¾-in. diameter aluminum tube, accommodates four charges per foot at 180° phasing. Small holes are provided in the carrier for the charge pivot screws and the motivating extension springs, while large apertures provide an egress for the charges as they swing from a vertical position when in the tubing to a horizontal position when in the casing. The top of each aperture is placed to provide stops for charges after they have pivoted 90°.

The shaped charges consist of the conventional copper liner, temperature resisting high explosive, and a booster, housed in a die cast aluminum container. Detents at the top and bottom of each container, lock the charges together and allow them to open in a train action after the bottom charge is released.

The carrier assembly is joined to the firing head by a cast aluminum connector which provides a clean break between the expendable and retrievable parts when the gun is fired.

Each charge is detonated by high temperature RDX primacord, tightly covered with Hycar tubing as a protection from well fluids. This primacord originates in the firing head and weaves back and forth between the charges, guided by the groove in each cap which assures contact between the primacord and charges for positive and effective detonation.

The primacord terminates in the bull nose, a die cast unit protecting the bottom of the carrier and guiding it past collars in the tubing. It also holds the electrically detonated release squib in place against the lower detent of the bottom charge, holding it, and thereby all the charges, in position until the squib is sheared off by a current initiated at the surface.

The sequence of events, which allows the charges to be first released and then fired, originates in the expendable, but retrievable, steel firing head. Here, in a sealed compartment, are housed the explosive devices employed in detonating the primacord, and the safety switch mechanism which delivers current to the release squib and the detonator in the proper sequence.

The safety switch is a double pole, double throw switch actuated by a plunger, which is controlled by the release arm. In its down position, the switch grounds the main detonator, as a safety measure, and transmits current only to the release squib, see Fig. 2. In the up position, current is transmitted to the detonator, exploding it, the booster and the primacord successively. To prevent premature actuation of the switch, the release arm is locked in a down position by the top charge until all the charges have been released to assume their firing position. The release arm then swings out of the carrier like a charge, moving through a 70° arc and then closing the switch to the detonator circuit. Any restriction of the arm to less than 70° of travel prevents the gun from arming unless previous adjustments of the firing head has been made to allow firing at a lesser angle. Since the firing head is the sole trigger for the gun and is not dependent upon any part of the tubing or casing to arm it, the gun, in this sense, is independent of the physical characteristics of the well in which it operates. Should an open gun be withdrawn from the casing, back into the tubing, the release arm and charges will be forced back into a vertical position by the bottom of the tubing, returning the detonator circuit to ground and rendering the gun harmless.

A dimensional drawing of the cable head, magnetic casing collar locator, and gun assembly is shown in Fig. 3.

Tandem Carriers

The detail of the tandem connection shown in Fig. 4 illustrates the method of joining carriers to make a single, long gun. By inserting a tandem connector between the carriers, a rigid unit is created, while conventional splicing methods allow continuity of the primacord and the squib lead wire. The system of interlocking charges is maintained by a tandem release arm which replaces a charge at the tandem interval. Several units may be joined to extend the tubing gun to any desired length with no reduction in the efficiency of the gun.

Skipping An Interval

In situations where it is necessary to perforate adjacent zones with a relatively narrow unperforated interval between them in a single run, it is possible to assemble a gun without charges at the interval to go unperforated. To accomplish this and still retain the simple release principle based on interlocking charges, it is necessary to install a blank interval device, Fig. 5. This device consists of two tandem release arms connected by a ⅛-in. OD aluminum rod which transmits the train action of the charges in one group to the charges of the other group, allowing the normal operation of the complete gun, yet keeping the volume of debris to a minimum. A continuous piece of primacord is used to detonate both groups of charges in a method identical to that in a fully loaded gun. It weaves through the grooves of the top group of charges, coils in the blank interval of carrier, (serving upon detonation to break this section into small fragments), and resumes its normal pattern with the bottom charges, terminating in the bull nose.

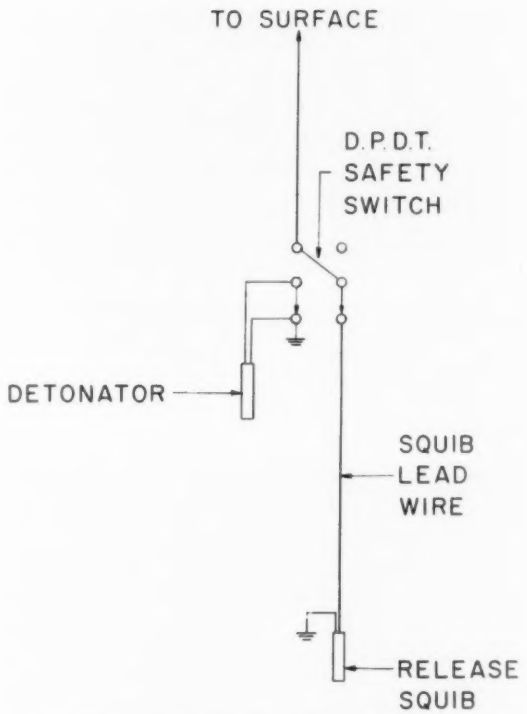

Fig. 2—Schematic Wiring Diagram Showing Safety Switch in Down Position.

SAFETY FEATURES

The swinging charges, which are the unique feature of this gun, are also the key to the safety of the mechanism because without their release it is impossible for the gun to fire. As was previously mentioned, the release arm at the top of the gun controls the firing switch. Prior to the actuation of the firing switch the detonator is grounded. Actuation of the firing switch can take place only after the top charge has released the arm and it has rotated to the set position. To confine the release arm to any position less than the set position, keeps the firing circuit continuously grounded. On the surface, an aluminum safety clamp is kept over the assembly, thus restricting the movement of the charges and the release arm. As soon as the gun enters the confinement of the lubricator, the lubricator takes over this function. At no time while the gun is in the lubricator or the tubing string is it possible for the release arm to swing out far enough to arm the gun.

If, after the gun has left the tubing, the charges are released and for any reason the gun fails to fire, it is an inherent characteristic of the design that they refold themselves into a locked vertical position inside the 1¾-in. carrier upon their re-entry into the 2-in. tubing. This action again grounds the firing circuit and the charges remain in this position until the gun is completely disarmed immediately upon the appearance of the firing head above the lubricator.

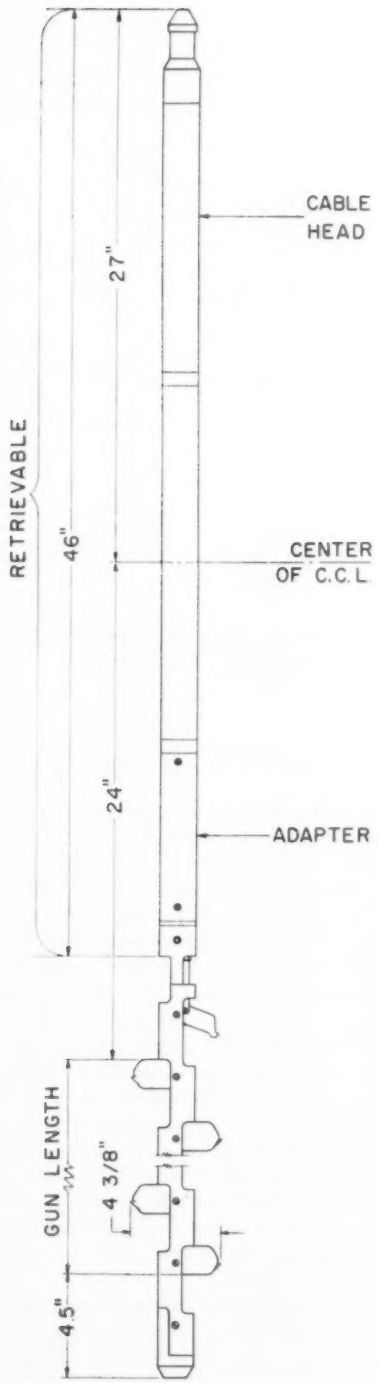

FIG. 3—DIMENSIONAL DRAWING OF COMPLETE TUBING GUN ASSEMBLY.

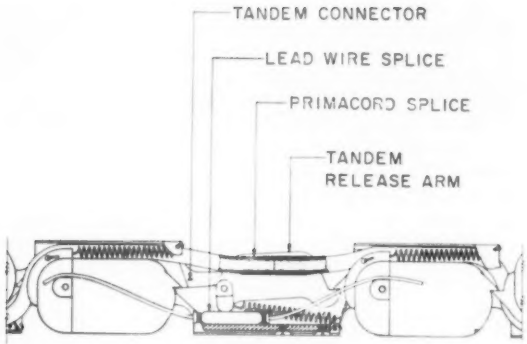

FIG. 4 — TANDEM CONNECTION.

PERFORMANCE

Laboratory tests were run to obtain performance data when firing through the maximum fluid possible in both 5½-in. and 7-in. casing. These tests were fired into prepared targets consisting of ⅜-in. steel plate of anyalysis and heat treatment similar to API N-80 casing, backed up by 43-day neat cement. Fig. 6 shows the results obtained by firing through ½-in. of fluid which simulates the condition of maximum clearance possible in 5½-in., 17-lb casing. The hole size is ½-in. with 9.1-in. penetration. Fig. 7 displays the results obtained when firing under fluid with 2-in. clearance, simulating the maximum clearance possible in 7-in., 23-lb casing. The entrance hole diameter in this case is 5/16-in. and the depth of penetration is 7.35-in. Fig. 8 illustrates the result of firing at the minimum angle of 45° where the OD of the gun is only 3⅝-in. Note the 0.53 x 0.60-in. diameter hole and 6.9-in. of effective (horizontal) penetration.

In an effort to evaluate the operation and performance of this new gun under actual well conditions together with resulting damage to unsupported casing, a series of field tests were arranged in an abandoned well on the Gulf Coast. This well contained 7-in. casing plugged at 7,000 ft and was filled with 11.6 lb mud. Separate target assemblies consisting of a 12-ft length of 5½-in., 17-lb casing, plugged at the bottom and connected by a perforated swage nipple to 2½-in. tubing, were run successively to depths of 5,000, 4,000, 3,000 and 2,000 ft. In each case a 4-ft section of the new perforating tool was lowered through the tubing on the wire line in the conventional manner and was positioned in the center of the 12-ft length of casing.

After firing, the tubing was pulled which enabled recovery of the debris, examination of position and location of holes and splitting effect on casing. Visual examination of all targets showed two rows of eight perforations 180° apart with all holes over ½-in. in diameter. The astonishing result shown by these tests was the minimum amount of damage to unsupported casing caused by the gun. The maximum splits around the holes were only hairline cracks extending approximately ½-in. from the perforation with many of the holes showing no cracks at all. The debris showed excellent breakup and a minimum fill-up, as expected, and in every case all debris was found in the bottom of the casing. The largest pieces recovered were from the

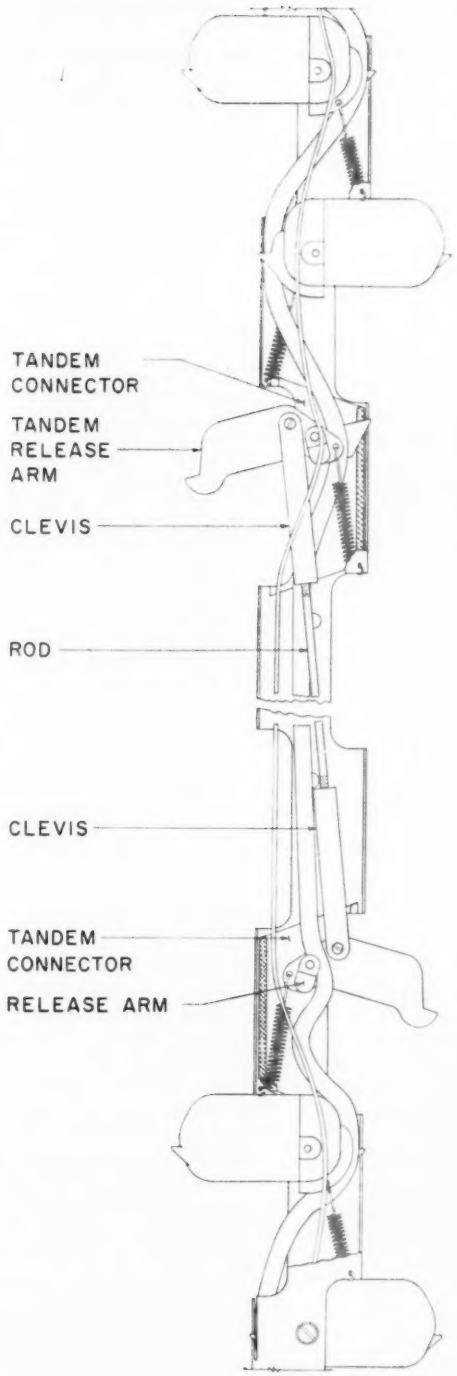

FIG. 5 — BLANK INTERNAL DEVICE.

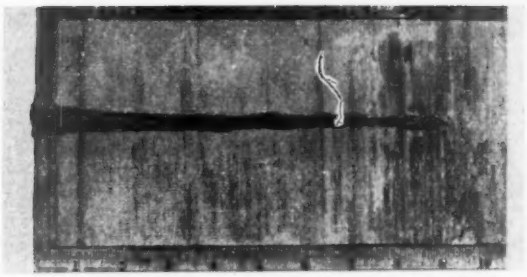

FIG. 6 — TEST SHOT THROUGH ½-IN FLUID AND ⅜-IN STEEL INTO 43-DAY OLD NEAT CEMENT. ENTRANCE HOLE 0.50-IN, PENETRATION 9.1-IN.

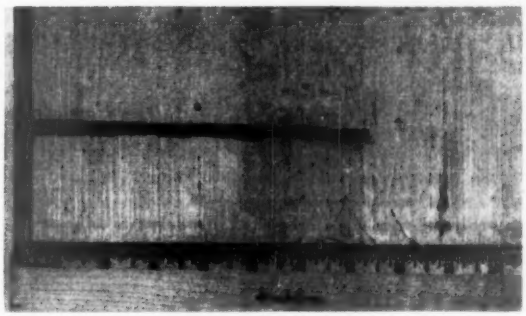

FIG. 7 — TEST SHOT THROUGH 2-IN FLUID (MAXIMUM CLEARANCE FOR THIS GUN IN 7-IN, 23-LB CASING). ENTRANCE HOLE 5/16-IN, PENETRATION 7.35-IN.

FIG. 8 — TEST SHOT AT 45° ANGLE. ENTRANCE HOLE 0.53-IN X 0.60-IN. TOTAL EFFECTIVE PENETRATION 6.9-IN.

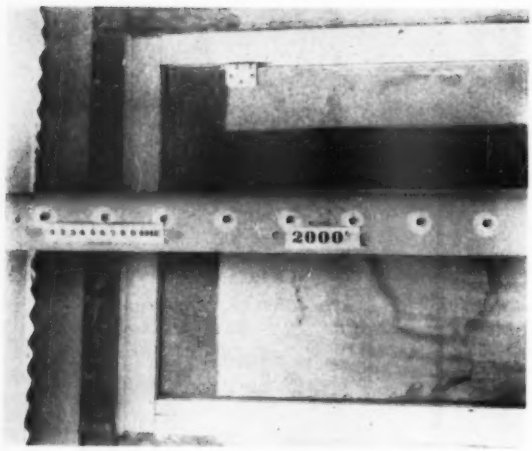

FIG. 9 — CLOSE-UP OF UNSUPPORTED 5½-IN, 17-LB, J-55 CASING SHOT WITH A 4-FT GUN AT 2,000 FT IN 11.6-LB MUD.

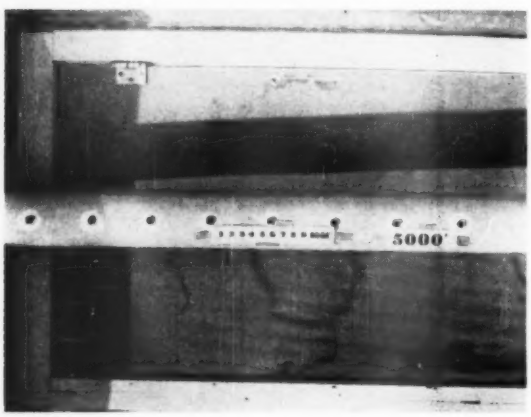

FIG. 10 — CLOSE-UP OF UNSUPPORTED 5½-IN, 17-LB, J-55 CASING SHOT WITH A 4-FT GUN AT 5,000 FT IN 11.6-LB MUD.

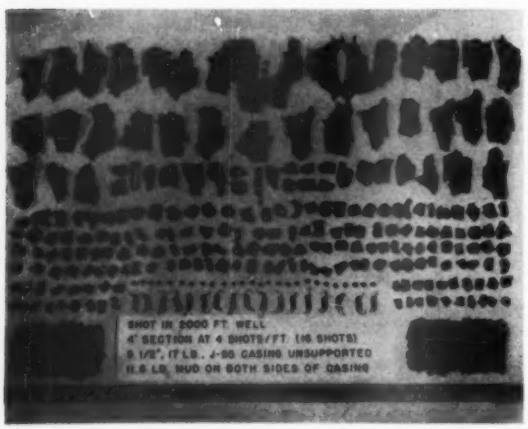

FIG. 11—DEBRIS FROM A 4-FT GUN RECOVERED FROM TEST TARGET SHOWN IN FIG. 9.

sand cast bull nose. This part has subsequently been redesigned as a die casting of one quarter the weight which has resulted in greatly improved breakup characteristics.

Figs. 9 and 10 show the casing from the 5,000 and 2,000-ft tests. Figs. 11 and 12 are photographs of the debris from these tests as removed from the test targets upon return to the surface. Fig. 13 is a composite photograph of all four sections of casing used in the test.

As representative of field results to be obtained with this new gun, the following brief resume of actual case histories are presented:

A well in the Gulf Coast had been perforated in October, 1953 with a conventional type tubing gun and was flowing 25 B/D at 200 psi tubing pressure. After perforating on Feb. 5, 1954 with this new gun, the pressure built up to 700 psi and production increased to 100 B/D where it has remained to date. The recorded bottom hole temperature of this well was 278° F.

In another Gulf Coast field, a major oil company had found all previous attempts to perforate a particularly hard formation with a conventional 1¾-in. tubing gun unsuccessful due to inadequate penetration. They had therefore established the practice of setting 2½-in. tubing to enable the use of the more powerful 2-3/16-in. conventional tubing gun. Upon agreement to use this new 1¾-in. tubing gun in a test, 2-in. tubing was set. Pressure built up immediately after the gun was fired, giving excellent results which were above expectations.

In still another field a well had been perforated twice before with a conventional 1¾-in. tubing gun and production was still unsatisfactory at 40 B/D at 50 to 75 psi flowing pressure. After perforating with 2 ft of the new gun, the tubing pressure built up to 900 psi and the well continued to flow at 90 B/D.

FIELD OPERATION

1. Gauging Tubing—Because of the nature of the construction of this gun it is not feasible to force it, either with weight or by "spudding," through restrictions in the tubing. To guard against possible damage to the gun and assure entry through the tubing to the zone to be perforated, it has proved advantageous to run a 1¾-in. OD tubing gauge equal in length to the gun, up to a maximum of 20 ft, prior to each shooting run. This practice will reveal any crooked or "tight" joints, excessive scale, or restrictions caused by special devices in the tubing and will allow remedial measures to be taken before the gun is run, resulting in lower costs and time saved.

2. Length of Gun—The standard length of this gun is 10 ft; however, the design is such that it can be cut to any desired shorter length. A tandem connector is employed where lengths in excess of 10 ft are required. To date wells have been successfully perforated with guns ranging from 6 in. to 45 ft in length. Fig. 14 is a view of this 45-ft gun in position just prior to being lowered into the well. This is by no means the maximum to which the gun may be extended as there is no reason that a single gun many feet in length could not be successfully fired.

Where guns of extreme length are used, and a derrick is present, they may be raised in one piece and lowered into the well. Where no derrick is available, 30-ft lengths of the gun may be raised with a gin pole and splicing done as the units are lowered into the well.

3. Fittings on Lower End of Tubing—For best performance in retrieving an opened gun, it is recommended that the lower end of the tubing be equipped with expendable tubing plug nipple or left plain. Swage fittings of any size should be avoided because of their detrimental effect upon the locking sequence of the charges.

4. Debris in the Well—Because of the mechanical action of this tubing gun in swinging its charges into firing position, it is desirable that the well fluid be circulated sufficiently to remove pieces of cement, rubber, lost circulation material, and other debris capable of interfering with the free movement of the charges. Removal of this material assures the gun of normal operation. Circumstances may arise in which it is impossible to circulate the well fluid sufficiently to remove this debris. In such cases it is possible to pack the gun with wheel bearing grease to eliminate the deposit of debris in the gun which would interfere with the proper opening of the charges.

5. Well Fluids—Well fluids must also be considered in conditioning the well for the tubing gun. Any acids in the well will have a highly detrimental affect upon the aluminum. Parts of the gun may be completely dissolved by acids left from acidizing operations as a result of insufficient circulation after the job. These acids must be removed or diluted to a degree that will render them harmless to the aluminum.

Extremely heavy mud presents another problem. This gun has been operated successfully in 13-lb, 200-viscosity, oil base mud in which the rate of descent was reduced to as low as 13 ft/min. It is far better, however, to provide a less viscous fluid to allow faster descent and greater ease in opening the charges to the firing position. It is recommended that water or oil be used as a well fluid.

6. Tubing Depth With Relation to the Perforating Zone—To reduce the possibility of complications resulting from the upward surge of force from the detonation of the charges, it is recommended that a minimum clearance of 15 ft be maintained between the bottom of the tubing and the top of the zone to be perforated. When this 15-ft minimum is used, the tubing should be kept full of fluid to provide a cushion.

7. Well Depth With Relation to the Perforating Zone—In its firing position, the bottom charge is less than 6 in. from the bottom of the gun, making it possible to perforate very close to the bottom of the well.

8. Shooting in Restricted Areas—In situations where it is known that the inside diameter of the casing has been appreciably reduced by a sheath of mud, cement, paraffin, or some other material, it is possible to adjust the firing head in the field to fire at intermediary angles below 90°.[6] At the lowest recommended angle of 45°, the outside diameter of the gun is 3⅝-in.

Statistics on the effective penetration perpendicular to the casing when firing at reduced angles of 45° and 70° are shown in Figs. 15 and 16 respectively.

9. Dissolving Debris in the Well—Because of the material and the excellent breakup characteristics of this gun, the fragments are dissolved more rapidly by

FIG. 12—DEBRIS FROM A 4-FT GUN RECOVERED FROM TEST TARGET SHOWN IN FIG. 10.

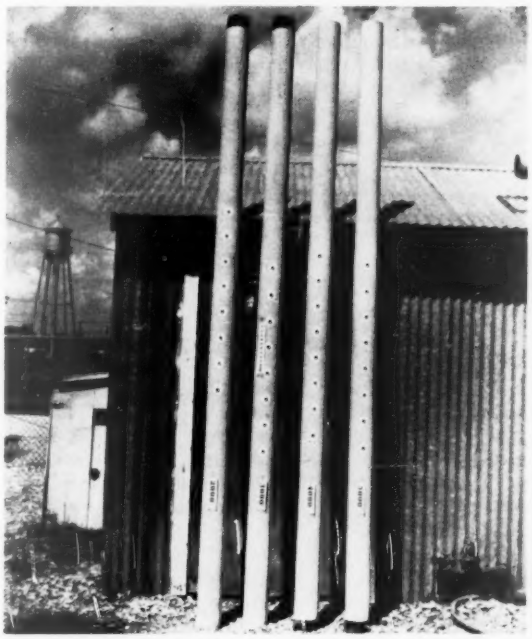

FIG. 13—RESULTS OF TESTS IN UNSUPPORTED 5½-IN. 17-LB CASING.

TABLE 1—SUMMARY OF WORK DATA

Using data compiled from the first 764 jobs performed to Nov. 1, 1954 with this tubing gun, the following information was derived:
Deepest Well—13,310 ft—2-in. tubing—5½, 20-lb casing—120 holes
Shallowest Well—645 ft—2-in. tubing—5½, 11.8-lb. casing—32 holes
Average Depth—6,192 ft.
Type of Completion—60 per cent workover
40 per cent new wells
Longest Gun—45 ft—180 charges at 9,961 ft—9⅞-in. hole—2-in. tubing, 5½-in., 20-lb casing
Shortest Gun—6-in.—2 charges at 5,349 ft—2-in. tubing—5½-in. casing
Average Length Gun—10 ft—40 charges
Greatest Number of Charges Shot in One Well—552
Casing Size—5½-in.—74 per cent
7-in.—20 per cent
Other—6 per cent
Highest Recorded Temperature—294° F
Highest Bottom Hole Pressure—8,400 psi
Highest Tubing Pressure at Which Gun Was Lowered Without Pressure Feed in Equipment—900 psi with 3/16-in. line and 600 psi with 7/16-in. line
Highest Tubing Pressure at Which Gun Was Lowered With Grease Tube Type Packoff—2,200 psi
Highest Tubing Pressure at Which 2,750 psi with 3/16-in. line and Gun Was Withdrawn from the Well—1,200 psi with 7/16-in. line

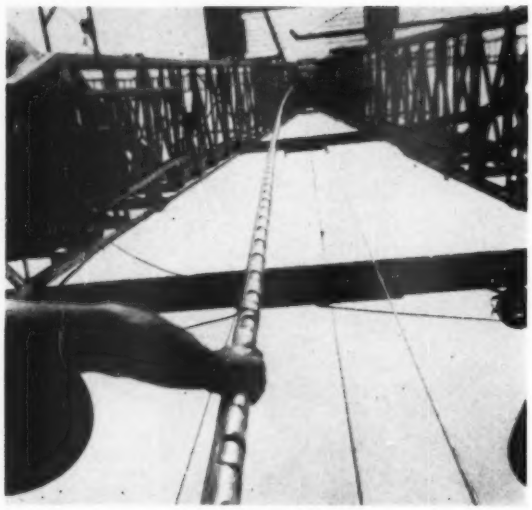

FIG. 14—A 45-FT GUN JUST PRIOR TO ITS ENTRY INTO THE WELL PERFORATED 9,961 FT. WELL FLOWED WITH 1,900 PSI PRESSURE.

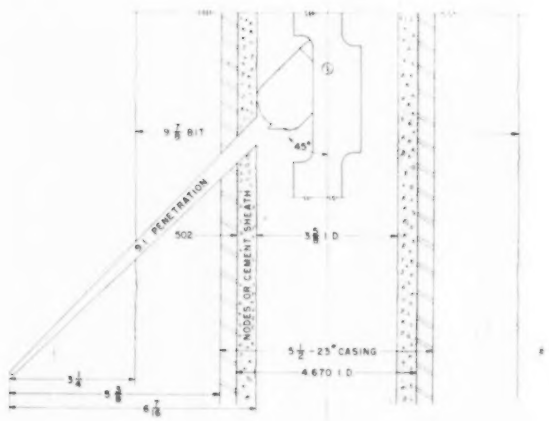

FIG. 15 — LATERAL PENETRATION OF TUBING GUN CHARGE IN RESTRICTED CASING AT 45 DEGREES.

FIG. 16 — LATERAL PENETRATION OF TUBING GUN CHARGE IN RESTRICTED CASING AT 70 DEGREES.

the well fluids. In cases where it is necessary to dissolve the debris immediately, a caustic solution may be used. In one instance, 500 lbs of caustic soda was mixed with 3½ bbl of water and this solution was pumped to the debris and allowed to remain one hour after which the solution was pumped past the debris at the rate of ¼-bbl every 15 minutes. This procedure dissolved the debris and left the casing free for perforating.

10. Wells Containing 1-25/32-in. ID Nipples—Wells containing Otis Type "J" landing nipples or 1-25/32-in. ID pump seating nipples in the tubing string have been successfully shot with this new gun. Because of the flexibility of the opened carrier as compared with the rigid sealed gun tubes in conventional type tubing guns, it is much easier to pass through these restricted areas. To assure the gun will pass through such a nipple, a 1.780-in. ID gauge is passed over the entire length of the assembly prior to running the gun in the well.

CONCLUSIONS

This new tubing gun, utilizing a swinging jet charge, has increased the scope and effectiveness of permanent-type well completion by providing:

1. A larger charge placed closer to the casing, resulting in larger hole size and greater depth of penetration.
2. Equipment capable of operating at pressures up to 10,000 psi and temperatures of 300° F.
3. Increased fragmentation of the expendable aluminum parts.
4. No objectionable casing damage.
5. Extra safety features not provided in any conventional perforators.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the Shell Oil Corp. and the Humble Oil & Refining Co. for their cooperation in field testing this equipment. They also wish to thank the Welex Jet Services, Inc., for permission to publish this data and to John J. Robertson and R. L. Robinson of this organization for their assistance and cooperation.

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DISPLACEMENT of OIL from POROUS MEDIA by MISCIBLE LIQUIDS

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ABSTRACT

The report describes scaled model experiments on the recovery of oil from porous sands by the injection of miscible liquids [solvents] and the subsequent recovery of the solvents by water flooding. Special attention has been paid to the scaling problem.

Scaling rules are deduced and their correctness is checked by carrying out experiments in tubes of various sizes.

Data are submitted on the effect of the viscosity ratio oil-solvent on the efficiency of the displacement process, the viscosity ratio varying from 1.5 to 5,000.

Breakthrough recoveries obtained when flooding with kerosene as a solvent, are equal to those obtained in water flooding at the same viscosity ratio, indicating that the phenomenon of viscous fingering is decisive. After breakthrough, however, flooding with a miscible liquid becomes much more efficient than a water flood and this is more pronounced as the viscosity ratio oil-solvent is higher.

Although high oil recoveries are obtained and most of the solvent in the sand can be recovered by a subsequent waterdrive, a straight flood with miscible liquids does not appear economically attractive because of the large quantities of solvent required. Therefore, a circulation process is introduced, the features of which are described in this paper. Though by means of this circulation process the amount of solvent required can be drastically reduced, the process is not yet economic.

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SCOPE OF THE INVESTIGATION

The recovery efficiency by water flood of oils of viscosities exceeding 50 cp is low. As interest in production of these highly viscous oils is growing at the moment, it was considered worthwhile to gain basic information on the feasibility of first flooding such oils with a low viscous miscible liquid [solvent] and subsequently producing the latter in a conventional way, e.g. by water flooding. The method has the obvious drawbacks that return on the investment is delayed until water flooding has begun and that it requires the investment of a more valuable product to produce a less valuable one. On the other hand, it may be expected that the displacement of one liquid by another is more efficient when the two liquids are miscible than when they are immiscible. As laboratory data on this point are scanty, the present investigation seemed justified.

Another argument for carrying out these experiments is that they present a valuable contribution to our concepts of the scaling problem in reservoir engineering studies. Some major difficulties which are encountered in the scaling of the waterflooding process such as the scaling of the capillary forces and the difficulty of obtaining the same permeability characteristics in the model do not present themselves in this case. As the fluids are miscible capillary forces do not play a role and as there is only one fluid phase, Darcy's law is valid in its original form. Consequently it is felt that the scaling rules can be deduced with a greater amount of certainty.

An essential feature of the experiments is that they are scaled model ones, which are, however, somewhat

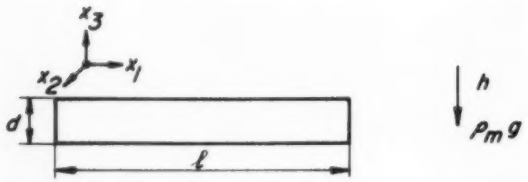

FIG. 1 — DIAGRAM ILLUSTRATING DIRECTION OF GRAVITATIONAL FORCE.

limited in scope in that they represent the rather ideal prototype of a homogeneous loose sand body completely saturated with a viscous oil that is subjected to a linear flood.

The experiments carried out can be divided into two groups:

1. Those carried out to obtain basic information on the displacement process only without considering any economic aspects. These experiments at the same time present a valuable contribution to our conceptions of the scaling problem in reservoir engineering studies.
2. Experiments in which the merits are evaluated of a procedure which aims at reducing the large amounts of solvent required in a straight flood for displacing the viscous oil. A recycling process is described in which the oil viscosity is gradually lowered until a viscosity level is obtained at which water flood can be successfully applied. In this way relatively small amounts of displacing miscible liquid may be sufficient. The cheapest displacing liquid will probably be a low viscous crude.

SCALING RULES

Experiments have been made in various horizontal cylindrical tubes [length l, diameter d], filled with sand of permeability k and completely saturated with oil of viscosity η_o. A miscible liquid [solvent] is injected at a constant rate of q at one end of the tube. The quantities of oil and solvent produced at the other end are measured.

Hydrodynamically our problem is governed by the equations of continuity and Darcy's law. If the oil is considered to be incompressible, the equation of continuity for it, taking diffusion of oil in solvent into account, may be written as:

$$-f\frac{\partial c_o}{\partial t}-\sum_i\frac{\partial}{\partial x_i}[c_o v_i]+fED_o\sum_i\frac{\partial^2 c_o}{\partial x_i^2}=0 \quad (1)$$

where $i = 1, 2, 3$.

Equation 1 obtains for an elementary cube, the dimensions of which are large compared to those of the pores. The v_i in the equation denotes a mean velocity component in a certain direction; in the pores, however, the direction of flow may be at angles to this mean flow direction. Thus the actual distance along which diffusion must occur is longer than in a non-porous medium. For this reason in the third term of Equation 1 the effective diffusion coefficient is indicated by ED_o, where D_o is the normal diffusion coefficient in a non-porous medium and E is a dimensionless factor which will be smaller than one and which depends on the pore configuration.

Apart from this addition of the factors E and f, Equation 1 is identical to the equation of continuity for fluid flow in a non-porous medium. The factor f has been added to take into account that v_i is defined as the superficial velocity in accordance with reservoir engineering practice.

By substituting

$$x_i = X_i d \text{ and } t = T\frac{d^2}{q} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

we can write the above equation in a dimensionless form:

$$-f\frac{\partial c_o}{\partial T}-\sum_i\frac{\partial}{\partial X_i}\left[\frac{c_o v_i d^2}{q}\right]+\frac{fED_o d}{q}\sum_i\frac{\partial^2 c_o}{\partial X s_{12}+e+X_i^2}=0 \quad . \quad . \quad . \quad (3)$$

A similar equation obtains for the solvent component, which can easily be found by replacing the index o in Equation 3 by s.

Also Darcy's law obtains

$$v_i=-\frac{k}{\eta_m}\left[\frac{\partial p}{\partial x_i}+\delta_i\rho_m g\right] \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where $i = 1, 2, 3$ and $\delta_1 = \delta_2 = 0$ and $\delta_3 = 1$ [Fig 1].

By introducing the same transformation (2), equation 4 can be written in a dimensionless form as follows:

$$\frac{v_i d^2}{q}=-\frac{\partial}{\partial X_i}\left[\frac{kpd}{q\eta_m}\right]-\delta_i\frac{\rho_m g k d^2}{q\eta_m} \quad . \quad . \quad (5)$$

From equations 2, 3 and 5 it is seen that the following dimensionless products pertain to our problem:

a. independent variables: $\frac{x_i}{d}$ and $\frac{qt}{d^2}$

b. dependent variables: $\frac{v_i d^2}{q}$ and $\frac{kpd}{q\eta_m}$

c. coefficients: $\frac{\rho_m g k d^2}{q\eta_m}$, $\frac{q}{D_o d}$, $\frac{q}{D_s d}$

Instead of the last two coefficients we may also introduce one of them and the ratio of the two viz. D_o/D_s.

It should be noted that f, c_o, c_s and E are dimensionless. Consequently, they may be left out of the dimensionless products if we consider it as an obviously necessary condition that porosity, initial saturation and pore configuration are the same in model and prototype. If this is done and scaling is correct according to the dimensionless products derived, then c_o and c_s will have the same value at each scaled time and in each scaled point in model and prototype. If, f, C_o, C_s and E are not identical in model and prototype, they should be included in the dimensionless groups in the same way as the other parameters.

The following relations also hold:

$$c_s = 1 - c_o \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$\rho_m = c_o\rho_o + c_s\rho_s \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$\eta_m = \eta_m[c_o, \eta_o, \eta_s] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

From equations 6 and 7 it follows that:

$$\frac{\rho_m}{\rho_o} = c_o + [1 - c_o]\frac{\rho_s}{\rho_o} \quad \ldots \ldots \quad (9)$$

Consequently ρ_m in $\frac{\rho_m g k d^2}{q\eta_m}$ may be replaced by ρ_o if the group $\frac{\rho_s}{\rho_o}$ is introduced as c_o will nowhere differ from its prototype value.

According to Equation 8 η_m can be written as $\eta_m = \Phi\left[\frac{\eta_o}{\eta_s}, \eta_s, c_o\right]$, where Φ is some [complicated] function. Therefore, in groups which contain η_m, it may be replaced by η_o if a new group η_o/η_s is introduced and η_s is taken equal to its value in practice, c_o being everywhere the same in prototype and model.

As the ratios η_o/η_s, ρ_o/ρ_s and D_o/D_s and in addition η_s must be the same in model and in prototype, *it is almost imperative to use the same liquids in both cases.*

One may wonder why the density of the mixture ρ_m can be replaced in the dimensionless group by ρ_o introducing only the ratio ρ_s/ρ_o, while η_m cannot be replaced by η_o without setting both the ratio η_o/η_s and η_s. The reason for this is that ρ_m/ρ_o is a function of ρ_s/ρ_o only, whereas such a simple relation does not exist between η_m/η_o and η_s/η_o.

The variables $\frac{v_1 d^2}{q}$ cannot easily be measured in our experiments as it involves a determination of the flow velocity components in each point of the tube. However, for the outflow end of the tube $\frac{v_1 d^2}{q}$ can be transformed into a more practical form. This is seen by multiplying with the dimensionless factor $1/4\pi c_o$, giving $\frac{1/4\pi d^2 c_o v_1}{q}$. The nominator of this group presents the oil production per unit time [q_o]. Thus the variable $\frac{q_o}{q}$ has been introduced, which is applied in its integrated form $\frac{\int q_o dt}{\int q dt} = \frac{R}{Q}$ where R is the quantity of oil produced and Q the total production [oil and solvent]. Both quantities are reported as percentages of the original amount of oil in place [= pore volume of the sand for an initial oil saturation of 100 per cent]. As oil and solvent are considered to be incompressible p can be replaced by $\triangle p$ [pressure difference across the tube].

Consequently, the result of an experiment can be reported by giving the dependent variables R [recovery] and $\frac{k \triangle pd}{q\eta_o}$ [dimensionless pressure number] as functions of the independent variable $\frac{qt}{d^2}$ [dimensionless time number]. Expressed in this way model and prototype should yield identical results, provided that the following dimensionless coefficients are the same:

$$\frac{q}{D_o d}, \quad \frac{\rho_o g k d^2}{q\eta_o}, \quad \frac{\eta_o}{\eta_s}, \quad \frac{\rho_o}{\rho_s}, \quad \frac{D_o}{D_s}$$

It will be clear that in order to have the same value in model and prototype the independent variables $\frac{x}{d}$ require the geometrical similarity between model and prototype.

TABLE 1 — VALUES OF THE VARIABLES FOR CORRECT SCALING OF VARIOUS FLOODING EXPERIMENTS WITH OIL (300 CP) AND KEROSENE (1.2 CP)

l	d	q	k
1.03 m	0.064 m	0.67×10^{-6} m³/sec	203×10^{-12} m² (203 D)
1.60 m	0.100 m	1.02×10^{-6} m³/sec	150×10^{-12} m² (150 D)
3.00 m	0.186 m	2.02×10^{-6} m³/sec	74×10^{-12} m² (74 D)

Assuming the linear dimensions of the model in which the same liquids are used as in the prototype, to be scaled down by a factor of a [$a > 1$] the first coefficient shows that q must be scaled down by the same factor, and the second coefficient shows that k must be scaled up by a. The dimensionless time number shows that t is scaled down by a^2, while from the pressure number it follows that $\triangle p$ is scaled down by a.

It is therefore possible to satisfy the scaling rules when using the same liquids as in the prototype.

SCALED EXPERIMENTS WITH VARYING LINEAR DIMENSIONS

To check the correctness of the scaling conditions discussed in the preceding section, experiments in which all of the dimensionless coefficients had the same value have been made in cyclindrical tubes of different lengths. The lengths of the tubes were 1.03, 1.60 and 3.00 m; their diameters were chosen so as to give equal $\frac{l}{d}$ ratios. The tubes were placed in a horizontal position and were all fully saturated with the same oil of 0.3 N sec/m^2 [300 cp].*

The displacing liquid was kerosene, viscosity 1.2 x 10^{-3} N sec/m^2 [1.2 cp]. The injection rates and the permeabilities were chosen in such a way that both $\frac{q}{d}$ and $k.d$ were [nearly] equal in all cases. It is easy to see that in that case also the dimensionless coefficients are [nearly] equal.

The values of q and k in the various experiments are given in Table 1.

The porosities of the sand were almost the same in the three cases [33 per cent to 36 per cent].

Fig. 2 shows the values of the dimensionless pressure $\left[\frac{k \triangle pd}{q\eta_o}\right]$ and the recovery of the original oil in place [R] plotted against the dimensionless time $\left[\frac{qt}{d^2}\right]$ for the three cases. It appears that the curves for the two largest tubes coincide satisfactorily, but that those for the smallest tube show appreciable deviations. The reason for this may possibly be that the diameter of the 103-cm tube [6.4 cm] is too small as compared to the grain size of the sand [0.07 cm].

To apply these results to a practical case, let us assume a scaling factor $a = 100$ for the 3.00-m tube.

*In the system used in this paper the units of mass, length, and time are kilogram, meter, and second, respectively. The corresponding unit of force is kg m/sec² called Newton (N).
1 N = 10^5 dyne; 1 N/m² = 10 dyne/cm² = 1.45×10^{-4} psi.
1 N sec/m² = 10 dyne sec/cm² = 10 poise.
1 m² = 1.013×10^{12} darcy.

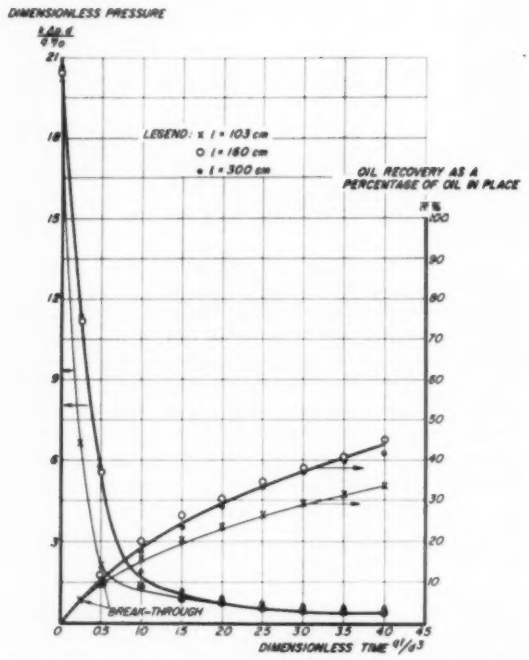
DIMENSIONLESS PRESSURE
LEGEND: x l = 103 cm
o l = 160 cm
• l = 300 cm
OIL RECOVERY AS A PERCENTAGE OF OIL IN PLACE
BREAK-THROUGH
DIMENSIONLESS TIME

FIG. 2 — DIMENSIONLESS PRESSURE NUMBER AND OIL RECOVERY AS A PERCENTAGE OF OIL ORIGINALLY IN PLACE VS DIMENSIONLESS TIME NUMBER FOR SCALED KEROSENE FLOODING EXPERIMENTS IN CYLINDRICAL TUBES.

The above results then obtain, for a linear flow in an oil sand of 300 m length, a thickness of 19 m, having a permeability of 750 md in which the injection rate is 17 m³/day. Breakthrough for this case will occur after about seven months.

From the figure it is seen that the pressure necessary to maintain the constant injection rate decreases very rapidly in the pre-breakthrough period. After that moment the decrease is far less pronounced.

EXPERIMENTS WITH VARYING VISCOSITY RATIO

According to results obtained by Croes and Schwarz[1] in water drive experiments, the viscosity ratio η_o/η_s can be expected to have a great effect on the recovery efficiency. To check this point, tests were carried out with η_o/η_s varying from 1.5 to 5,000. Again a kerosene viscosity 1.2 cp was used as the displacing fluid. In view of the results described above, these tests were made in the 1.60-m tube. To obtain a good comparison with the water drive experiments mentioned, the same sand having a permeability of 200 x 10^{-12} m² [200 D] and the same linear velocity [v = 2.3 x 10^{-4} m/sec corresponding to q = 1.8 x 10^{-6} m³/sec] were used. Results are given in Fig. 3 where the oil recovery is plotted against log η_o/η_s at different stages of production. As parameter for characterizing the production stage, the total production of oil and kerosene as a percentage of the pore volume (Q) is issued. The figure also shows some curves obtained in the waterdrive tests referred to above.

[1]References given at end of paper.

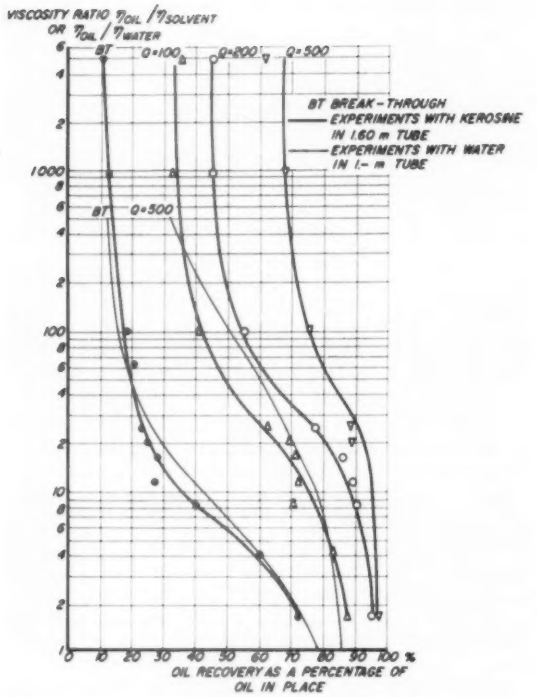

FIG. 3 — OIL RECOVERY WITH SOLVENT FLOODING, AS DEPENDENT ON THE VISCOSITY RATIO OF OIL AND SOLVENT COMPARED WITH OIL RECOVERY FROM WATER FLOODING TESTS ACCORDING TO CROES AND SCHWARZ. SOLVENT USED: KEROSENE, VISCOSITY 1.2 CP. CURVES ARE GIVEN FOR VARIOUS VALUES OF THE GROSS PRODUCTION Q [OIL + KEROSENE OR WATER] EXPRESSED AS A PERCENTAGE OF THE OIL ORIGINALLY IN PLACE.

It is seen that the breakthrough recoveries are nearly the same in both cases. Thus it is concluded that in this range the breakthrough recoveries are determined by the same phenomenon, namely, viscous fingering. After breakthrough of the displacing liquid, however, flooding with a miscible liquid becomes much more efficient than a water flood and this is the more pronounced as the viscosity ratio is higher. Apparently diffusion does not play an important role in the pre-breakthrough period, and can only make itself felt after prolonged flooding.

It has been claimed[2] that when displacing an oil by a miscible liquid a region exists in which the oil concentration increases gradually from zero to one in the direction of flow. The length of this transition zone is said to remain unaltered while it travels through the sand, thus acting as a plunger between the displacing and the displaced liquids. The length of this zone under field conditions is claimed to be of the order of 10 m, which is small compared to a well-distance of say 300 m.

As the results of the experiments in the two largest tubes tend to prove the correctness of the scaling rules, the length of the transition zone should consequently be of the order of 0.10 m for our 3.00-m tube. Accordingly a breakthrough recovery of the order of $\frac{300-10}{300}$

TABLE 2 — RESULTS OF FLOODING EXPERIMENTS WITH OIL AND KEROSENE FOLLOWED UP BY A WATER DRIVE

η_o/η_w	Total amount of kerosene used in per cent of pore volume	Ultimate oil recovery after water flooding in per cent of pore volume	Amount of kerosene in per cent of pore volume left in sand pack after water flooding
24	650	95	15
103	650	82	10
925	650	77	11
4960	650	68	17

or 96 per cent should be expected. The breakthrough recoveries found in our experiments are much lower in the whole range of viscosity ratios investigated. As, moreover, flooding phenomena in the pre-breakthrough period appear to be similar to those in water-oil displacement tests where no plunger action exists, it is concluded that the assumption of a transition zone is not valid in displacements of oil by miscible fluids for the range of viscosity ratios larger than one.

After injection of an amount of kerosene of 6.5 times the pore volume, water was injected at the same rate. This produced a mixture of oil and kerosene, which, however, largely consisted of kerosene. Water flooding was continued until the water/oil mixture ratio equalled 20.

Results are shown in Table 2, where the produced quantity of viscous oil and the amount of kerosene left in the sand pack are given.

Evidently, high ultimate oil recoveries are obtained, also in the case of very viscous oils. Further, most of the solvent [kerosene] in the sand is recovered by the water flood.

However, a straight flood as applied in these experiments requires large quantities of solvent. A method by which to reduce these amounts, will be described below.

EXPERIMENTS WITH RECIRCULATION OF PRODUCED MIXTURE

When considering the results given in Table 2 it should be borne in mind that they were obtained after prolonged flooding with kerosene. Consequently, if we think of a commercial process, enormous amounts of kerosene would have to be injected, which afterwards would have to be separated again from the oil by distillation, thus rendering the whole process uneconomic.

In the flooding experiments described above it was found that after breakthrough the kerosene content of the mixture produced increases rapidly.

The economy of the process can therefore be improved by introducing the following procedure: After breakthrough of the solvent part of the outflow is reinjected, the remaining part is withdrawn from the circuit [bleeding] and replaced by the same amount of pure kerosene. This recycling process is continued until the viscosity of the resulting mixture in the sand has been lowered sufficiently for successful application of a water flood. Results of an experiment are given in Fig. 4.

Before breakthrough the outflow is homogeneous and its viscosity equals that of the original oil, then suddenly "schlieren" occur and the mean viscosity of the [inhomogeneous] outflow drops from 1.10 to 45 x 10^{-3} N sec/m² [1,100 cp to 45 cp]. Without recirculation this decrease in viscosity would continue; if, however, recirculation starts as in the test of Fig. 4, the viscosity of the outflow rises again owing to the increase in viscosity of the displacing fluid. Consequently, the viscosity

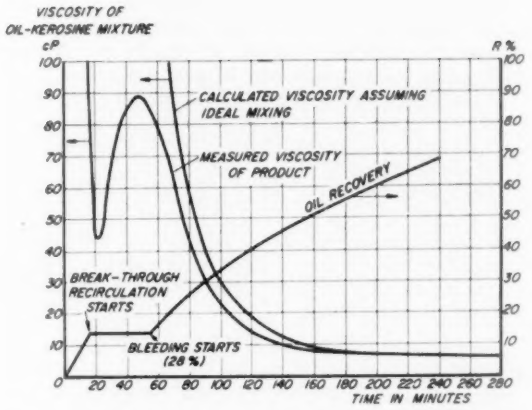

FIG. 4 — RESULTS OF A RECIRCULATION EXPERIMENT.

ratio of oil in place and displacing liquid will drop, which in its turn results in a more effective production of viscous oil.

As soon as bleeding is started and fresh kerosene is added to the inflow the viscosity of the outflow will again decrease rapidly. In Fig. 4 a curve is also drawn representing the viscosity of the mixture in the sand pack, calculated on the assumption that the pure kerosene injected is completely mixed up with the remaining original oil. It is seen that already after 170 minutes the two viscosity curves coincide, indicating that at that moment mixing was almost complete. Continuing recirculation would now become less effective as the viscosity drops only slowly and depends on the amount of fresh kerosene injected into the system. At this stage water drive should be started.

A series of experiments were carried out to study the influence of two variables, viz. the time of recirculation until bleeding starts and the fraction of the outflow which is continuously withdrawn from the circuit after bleeding has started.

From these experiments the following conclusions were drawn:

1. There is only a slight difference in results when bleeding started immediately after breakthrough and when it is started after 100 per cent PV has been recirculated. There is, however, a distinct influence of the degree of bleeding, less bleeding resulting in a markedly smaller amount of kerosene needed, without appreciably diminishing the ultimate recovery.

2. Water flooding should start as soon as possible, i.e., as soon as more or less homogeneous mixing of viscous oil and kerosene has been obtained. It is of interest to compare also the viscosity curves in Fig. 4, from which it is seen that as soon as 170 minutes after the beginning of the test practically homogeneous blending occurs.

3. The most salient fact, however, is that the economy of the procedure is much greater when applying recirculation.

From Table 2 it is seen that without recirculation 650 per cent PV of kerosene had to be used to reach an oil recovery of 77 per cent PV for a 1,100 cp oil,

while with recirculation a recovery of 81 per cent with only 48 per cent PV of kerosene could be obtained; the amount of kerosene lost was practically the same in both cases [11 per cent and 10 per cent respectively]. Yet the above figures show that to produce 100 m^3 of a highly viscous oil 59 m^3 of kerosene [or low viscous crude] must be used, of which 47 m^3 can be recovered by distillation and 12 m^3 are lost.

Though consequently the process may not be attractive for the moment it should be borne in mind, that the production of viscous oils will always involve extra costs. The process may further be of value for obtaining a bypass to start some other recovery process [underground combustion].

CONCLUSIONS

1. Model experiments on the displacement of oil by miscible liquid [solvent] should not be carried out on too small a scale. In the tests reported results with tubes of 1.60 and 3.00 m length were in good agreement, whereas those with a 1.03-m tube showed appreciable deviations.

2. Breakthrough recoveries obtained when flooding oils of different viscosities with kerosene as a solvent in unconsolidated sands are equal to those obtained in water flooding. When continuing the flooding process kerosene yields appreciably higher recoveries than water especially in the case of higher viscous oils. The drawback of a "straight" kerosene flood is, however, that large quantities of this solvent are required.

3. By applying a procedure in which after breakthrough the outflowing liquid is recirculated for some time, the amount of kerosene required can be drastically reduced without decreasing the oil recoveries. Though the procedure may be a potential bypass to start some other recovery process it is not yet an economic proposition.

ACKNOWLEDGMENT

The authors are greatly indebted to Jan van Heiningen for many valuable discussions, to A. Achterberg, J. A. van Benten, and J. Toornvliet for carrying out the experiments and to the management of N. V. De Bataafsche Petroleum Maatschappij, The Hague, for their permission to publish this work.

NOMENCLATURE

f	= porosity
c_o, $[c_s]$	= concentration of oil [solvent] in the mixture oil-solvent [m^3/m^3]
η_o, $[\eta_s]$ $[\eta_m]$	= viscosity of oil, [solvent] [mixture] [N sec/m^2]
ρ_o, $[\rho_s]$ $[\rho_m]$	= density of [oil], [solvent], [mixture] [kg/m^3]
D_o, $[D_s]$	= diffusion coefficient of oil [solvent] into solvent [oil] [m^2/sec]
E	= ratio of diffusion coefficient in a porous medium and the normal diffusion coefficient in a non porous medium
k	= one-phase permeability [m^2]
x_1, x_2, x_3	= Cartesian coordinates
X_1, X_2, X_3	=dimensionless coordinates
l	= length parallel to flow direction [m]
d	= length perpendicular to flow direction [m]
t	= time [sec]
T	= dimensionless time
q	= flow rate [m^3/sec]
g	= acceleration of gravity [m/sec^2]
p	= pressure [N/m^2]
$\triangle p$	= pressure difference [N/m^2]
v_1, v_2, v_3	= components of flow velocity [m/sec]
R	= oil recovery as a percentage of original oil in place
Q	= cumulative production [oil and solvent] as a percentage of original oil in place

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DISCUSSION

R. A. MORSE
MEMBER AIME

STANOLIND OIL & GAS CO.
TULSA, OKLA.

The authors conclude that in a miscible fluid drive in the range of viscosity ratios larger than one, there is no transition zone formed separating the injected and in-place fluids. This conclusion is based on the results of scale experiments in which a large prototype is studied by means of a small model. Our opposite conclusion has been reached based on laboratory tests on long core systems, flooded at oil field rates. Thus no scaling down of either time or distance is involved.

In core systems up to 100 ft in length, a more viscous oil was driven with a less viscous hydrocarbon (solvent). It was found that a transition zone was formed, which separates the in-place oil from the solvent. This zone was observed to grow rapidly at first, then gradually the rate of growth fell off to where it became nearly stabilized. As an example, in a 100-ft core system in which a 1.2 cps viscosity oil was pushed at a rate of advance of 2 ft per day by a solvent having 0.24 cps viscosity (viscosity ratio = 5), the transition zone was 5 ft long after traveling 10 ft, but after traveling 100 ft the zone was only about 10 ft long. The length of this zone was found to be influenced by its rate of advance, distance traveled, but most of all by the viscosity ratio and absolute viscosity of the fluids. Permeability of the porous material was found to have only a small effect on the length of the transition zone. Tests were run in an unconsolidated core system (2 darcys) and two consolidated core systems (400 md and 12 md).

It is a possibility that the work of the authors' is a study of the initiating stage of development of the transition zone. Our experience agrees with that of the authors for this phase of miscible fluid displacement in that the behavior during the initial phase is similar to immiscible fluid displacement. The scaling criteria that were used apparently are not complete enough to include the factors which control the formation of a transition zone.

AUTHORS' REPLY to R. A. MORSE

R. A. Morse's experiments are very valuable, especially as they are carried out in such very long cores.

There seems to be, however, an explanation which agrees with both our and his experimental results. In a cylindrical core with laminar flow in the longitudinal direction, diffusion has two effects. In the longitudinal direction it prevents the formation of a clear interface; in the radial direction, however, it helps in removing the original liquid which is trapped between "fingers" of the solvent. This promotes the formation of a more-or-less clear interface or transition zone. In the present case longitudinal diffusion can be safely neglected with respect to the large convection in that direction.

Consequently, the results we get will largely depend on whether the time which is required for diffusion to reduce radial variations of concentration to a negligible amount is small or large compared to the time necessary for longitudinal transport to produce such variations or fingers. This viscous fingering is likely to be especially important for high viscosity contrasts. Once fingers have been formed, some of them may grow rapidly to large dimensions until they are either confined by the boundaries of the reservoir or by other fingers. Thus, we believe the lateral dimensions of the fingers will be greater, the greater the width of the reservoir. Spreading out the finger boundary within which the concentration variation occurs must proceed by radial diffusion. Thus, the time required to eliminate the fingers will be proportional to d^2/D_m where d is diameter of the tube and D_m is the diffusion coefficient. Also, the time to produce a finger will be proportional to L/v where v is linear velocity and L the length the displacing fluid has traveled along the tube. The governing dimensionless group is consequently d^2v/D_mL. If this number is small, radial diffusion is relatively important and promotes the formation of a transition zone within which there is little or no radial variation in concentration. If it is large, diffusion will not play a significant role; and the effect achieved equals that obtained with immiscible liquids, i.e., viscous fingering.

Now, in Morse's experiment the values of v, D_m, and L are of the same order of magnitude as those in the field, but the lateral dimension d is greatly reduced as he uses a core, and this decreases the magnitude of the dimensionless number. Consequently, after traveling some length through the core a transition zone as described can develop. This, however, would not occur in the field where d is much larger and lateral diffusion cannot make itself felt over such a large distance in the time available. In the long core experiment the longitudinal distance is not scaled down, but the lateral distance is scaled down by a large factor. By giving both d/l *and* q/D_md the values occurring in the field, we gave also the number d^2v/D_mL the right value ($q = \frac{1}{4}\pi d^2v$).

This also explains why in the initiating stage Morse's results agree with those given in the paper. The length L over which the fluid is displaced is still very short and the number d^2v/D_mL has still a low value; radial diffusion has not yet had time to make itself felt, and radial variations in concentrations or fingers still exist. Or, in other words, the ratio d/L still complies with that used by us.

In the later stage of Morse's experiment radial variations in concentrations are negligible, and there results a continuous concentration variation in longitudinal direction forming a transition zone between pure solvent and pure oil. Such a transition zone has a stabilizing effect in that it will prevent further viscous fingering. Viscous fingering can only be expected if there exists a large contrast in viscosity between two adjacent fluids, and this condition only occurs at the start of Morse's experiment.

It is, however, exactly that initiating stage which will occur in the field, and the stabilizing transition zone will not get time to develop before breakthrough to the production well occurs. ★★★

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P. R. SCHULTZ recently became president of Blackwell Oil and Gas Co. in Tulsa, Okla. Prior to accepting this position, he was manager of chemical plants for Stanolind Oil & Gas Co. He has been with Stanolind and Standard Oil Co. (Ind.) for approximately 15 years. Blackwell Oil & Gas Co. is an independent producing company operating 223 producing wells in the Southwest and holding interest in the Rocky Mountain area. Schultz is a former chairman of the Petroleum Branch and is now a member of the Executive Committee representing MIED.

★

Oil and Gas Property Management, Inc., has elected an executive vice-president and three vice-presidents. C. C. (Mike) HARTER, JR., of Dallas has been named executive vice-president. LEE J. THRONSON, Dallas, HARRY LEYENDECKER, Houston, and GLENN ECKEL, Amarillo, are the new vice-presidents. This company now owns or operates some 700 wells in seven states.

★

A. J. KANGERS, Kansas district manager in charge of Perforating Guns Atlas Corp.'s Great Bend station, is now supervising service for the new PGAC field station at Liberal, Kans. Other new PGAC field stations have been opened at Perry, Okla., and at Healdton, Okla.

★

E. T. HECK is now assistant vice-president and manager of production and engineering for the Minard Run Oil Co. in Bradford, Pa. Formerly he held the position of chief of geology and engineering with the same company.

★

LLOYD C. GIBSON has retired after serving as an engineer in the tax department of Standard Oil Co. of New Jersey since 1934. From 1919 until 1922 he was a geologist with Standard of New Jersey; then, from 1924 until 1933 he was with the U. S. Treasury Dept. Income Tax Unit. For eight years he was chief of the Oil and Gas Section of this Unit. He has been a member of the AIME since 1921, having served from time to time on the Admissions Committee. For 20 years he served on petroleum industry federal tax committees as a specialist in depletion and related matters.

★

The Lafayette, La., consulting firm of Bates & Cornell, will terminate its activities as a partnership on Jan. 1, 1955. The firm is composed of DREW CORNELL and PAUL MONTGOMERY, petroleum engineers, and FRED W. BATES, JAY B. WHARTON, JR., ROBERT R. COPELAND, and MARK W. MITCHELL, petroleum geologists. The former partners will operate as individuals, and all previous functions as consultants, and as an independent operator, will continue. The same technical and field staff will be maintained. A company will be formed for the purpose of operating properties for themselves and others.

MATTHEW B. RIORDAN has been named vice-president in charge of engineering, research, and development of BJ Service, Inc., a wholly owned subsidiary of Byron Jackson Co. He will head the expanded engineering services of the company with an enlarged staff and newly constructed facilities at Long Beach, Calif. He has been with Byron Jackson since 1941.

★

EARL E. WALL has joined the staff of The Louisiana Land and Exploration Co. in New Orleans as petroleum engineer. Previously, he served with Brown Brothers, *et al.*, as field petroleum engineer at Post, Tex.

TENTATIVE PROGRAM

PETROLEUM BRANCH ACTIVITIES

AIME Annual Meeting, Conrad Hilton Hotel, Chicago

February 12-17, 1955

Saturday, February 12

AIME Council of Section Delegates Meeting 10 a.m.

Sunday, February 13

AIME Board of Directors Meeting at 2 p.m.

Monday, February 14

Morning—Open Meeting, Petroleum Branch Executive Committee.
Afternoon—Annual Production Review Session.

Tuesday, February 15

Morning—Technical Session.
Afternoon—Technical Session.
Evening—Annual Petroleum Branch Dinner.

Wednesday, February 16

Morning—Technical Session.
Evening—AIME Annual Banquet and President's Reception.

AIME President in 1959 May Be Petroleum Member

It is likely that a petroleum man will be president of the AIME in 1959. A mining man would take office that year in the usual rotation, but because 1959 is the 100th anniversary of the petroleum industry in this country, it is felt that a representative of that industry as president would be appropriate.

The Mining Branch Council has given its assent, provided a mining man would be selected for the presidency in 1960 and 1961. The probable rotation will therefore be: 1955, Mining; 1956, Petroleum; 1957, Mining; 1958, Metals; 1959, Petroleum; 1960 and 1961, Mining; and 1962, Metals.

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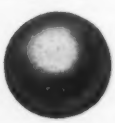
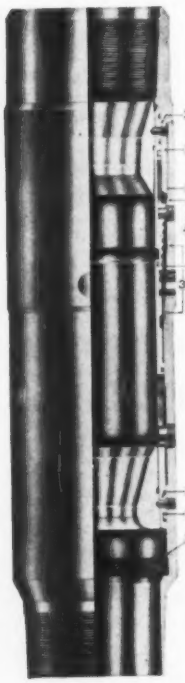


Weighted Trip Ball



When closed, the tapered sections (3 and 4) provide a steel-to-steel closure.

Now you can depend on more efficient stage cementing with utmost simplicity and positive assurance of a successful job.

The Two-Plug Stage Cementer employs the basic principles of the Rector Fulbore Cementing Method. Four 1¼" ports in the cementer are opened by a weighted trip-ball which seats in a baffle and shears the inner sleeve pins at approximately 600 psi. After this is done the cement slurry is pumped down the casing between two piston-like plugs which positively prevent contamination. Cement flows into the annulus behind the casing through the four 1¼" ports. These ports are closed by a trip attached to the lower end of the top plug.

All internal steel parts of the cementer are full opening . . . all internal aluminum parts, as well as plugs and trip-ball, are drillable.

Ask your nearest Rector Representative for complete information of the Two-Plug Stage Cementer or write for fully illustrated and descriptive bulletin.

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STUDENT CHAPTER FORMED; OFFICERS ELECTED FOR YEAR

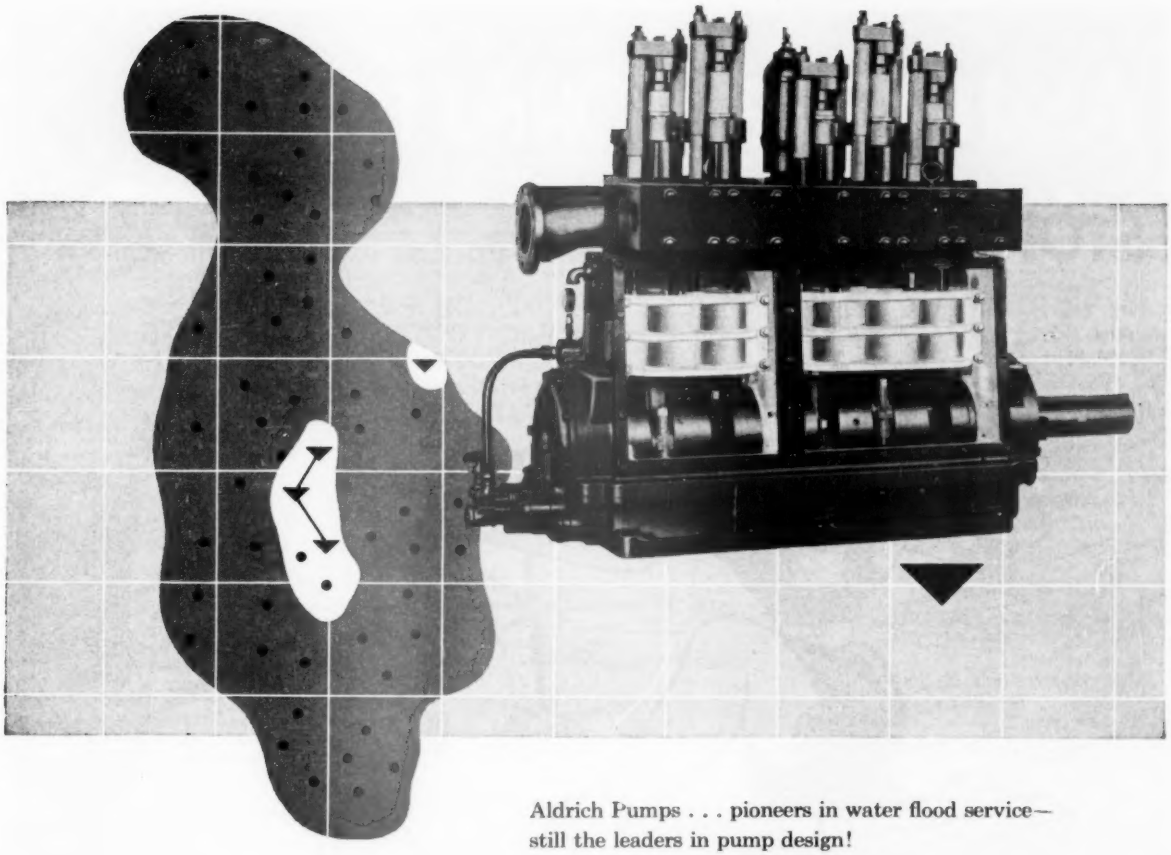
The West Virginia University Student Society of the AIME, Petroleum Branch was organized at a recent meeting of petroleum engineering students at this University. For several years prior to this reorganization the Student Society of the AIME has functioned for both mining and petroleum students. Officers for the new Petroleum Branch Student Chapter are R. M. Rupert, president; B. S. Welton, vice-president; and D. G. Warner, secretary-treasurer. R. W. Laird, associate professor of mining engineering, is the faculty sponsor.

The recent initiation of 47 new members has brought the total active membership to 108 persons in the Oklahoma A&M Petroleum Engineering Club, an AIME affiliate society. Joint monthly meetings are being held with other engineering societies on the campus, in addition to the club's regular meetings.

Officers for this semester are: Truman Branscum, president; Don Horton, vice-president; Dale Easterwood, treasurer; Joe Newman, recording secretary; Roger Utley, tool pusher; and A. T. Woods, Petroleum Department instructor, sponsor. O. L. Smith, of the Sun Oil Co. in Tulsa, is industrial advisor to the club.

Officers for the University of Tulsa Student Chapter have been elected for the 1954-55 school year. They are: Robert L. Maple, president; Edward E. Runyan, vice-president; Donald D. White, secretary; and Billy J. White, treasurer.

University of Oklahoma Student Chapter officers have been elected for the 1954-55 academic year. They are: Max Edgar, president, Perry, Okla.; J. B. Brininstool, vice-president, Jal, N. Mex.; Howard Geier, secretary, Keowa, Alberta, Canada; and Robert Beamish, treasurer, Moose Jaw, Saskatchewan, Canada. Engineering Open House Chairmen elected were R. H. Swarthout, of Hobbs, N. Mex., and Jerry Brandom, Oklahoma City. Keith Farries of High River, Alberta was chosen St. Pat's Council Representative, and Tom McCasland of Duncan, Okla., was elected to the chairmanship of the Entertainment Committee.



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YO' MEAN THEM THRILLIN' WORDS 'BOUT HOW WE JOHNSTONS DO TH' FINEST TESTIN' JOB, BECUZ O' TH' HYDRAULIC TESTER, THAT PREVENTS SHOCK T' FOR-MAY-SHUN, PIPE, AN' INSTRUMENTS!!
NO!!-THOSE EVEN MORE THRILLIN' WORDS, 'BOUT--
'BOUT HOW TH' HYDRAULIC TESTER GIVES YO' POSITIVE OPER-AYSHUN EV'RY TIME?-
PSST!!-AH THINKS SHE MEANS---
OH!!-NATCHERLY!!-
MERRY CHRISMUS T' YO'!!
-AN' YO'!!
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Proposed for Membership, Petroleum Branch, AIME

TOTAL AIME membership on Oct. 31, 1954, was 21,569; in addition 1,782 Student Associates were enrolled.

PETROLEUM BRANCH ADMISSIONS COMMITTEE

F. G. Prutzman, chairman: J. H. Sullivan: F. C. Kelton: C. C. Harter: Virgil Harris: Charles Hudson.

INSTITUTE ADMISSIONS COMMITTEE

O. B. J. Fraser, chairman; R. B. Caples, vice-chairman; F. A. Ayer, A. C. Brinker, R. H. Dickson, Max Gensamer, Ivan A. Given, Fred W. Hanson, T. D. Jones, Sidney Rolle, J. H. Scaff, John T. Sherman, F. T. Sisco, Frank T. Weems, R. L. Ziegfeld.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who ar eunqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/ means change of status: R, reinstatement; M, Members; J, Junior Member; A, Associate Member; S, Student Associate.

California

Brea — Atkins, Earle Richardson (C/S-J-M).

Oildale — Sears, D. H. (R, C/S-J-M).

Illinois

Carmi — Kincaid, Eugene E. (R, C/S-S-A).

Flora — Furber, Frederick Dwight (M).

Kansas

Great Bend — Nichols, James Ray (J).

Liberal — Howes, Wallace A., Jr. (C/S-J-M).

Wichita — Wilson, John Hoffman (M).

Louisiana

New Orleans — Sirgo, Manuel Andrew, Jr. (J).

Waterproof — Goudeau, Willie Adolph (R, C/S-J-M).

Montana

Butte — Harnish, Douglas Henry, Jr. (M).

New Mexico

Hobbs — Albright, John Douglas (J); Evans-Lombe, Walter Richard (J); Maxwell, Oliver Terrell (J).

New York

Bronxville — Witherspoon, Gavin (M).

Oklahoma

Duncan — Green, Daniel Paul (M).

Norman — Salisch, Henry Alfred (J).

Oklahoma City — Asay, Clinton Ted (J); Sengel, Edward William (M).

Ponca City — Mead, William A. (M).

Tulsa — Ford, Clarence Edward (M); McHugh, Jerome Pinckney (J).

Pennsylvania

Pittsburgh — Ferguson, William Henry (R, C/S-S-J); Wood, Robert Stevens (M).

Verona — McDowell, James Milton (C/S-S-M); Peters, Charles Jack (J).

Texas

Abilene — Canady, James Maurice (J).

Alice — Findley, William Edward, Jr. (M); Teal, Alvin P. (M).

Amarillo — Lorenzen, Robert Myron (J).

Breckenridge — Sweeney, Henry Nunn (M).

Coleman — Brannon, Mark J. (M).

Corpus Christi — Black, Clarence Wendell (M); Lamont, Norman (C/S-J-M); Ring, Kenneth Alvin (M); Statton, James Noble (A); Waters, Warren Kersey (M).

Dallas — Cleary, Tyson, Jr. (M); Holtrah Victor Martin (J); Otis, Herbert C. J. (A); Pela, Emil Cecil (A); Rollow, Wray Allen (A); Roth, Robert Irven (M).

Dollarhide — Murphey, John R., Jr. (R, C/S-S-J).

El Paso — Bennett, Jules Gordon (A).

Fort Worth — McGinnis, Jack Orvin (J).

Houston — Bricaud, Joseph M. (M); Brown, William Oliver (J); Christanelli, Fred Alex. (A); Cooke, Claude Everett, Jr. (J); Daughtry, Arthur Clarence (J); Dobson, Richard James (R, M); Gamble, J. L. (M); Harris, John Wylie, Jr. (J); Mullinax, James Arthur (M); Pilcher, Mason Johnson (M); Ward, Robert Dee (J).

Jacksboro — Macfarlane, James Laurence (R, J).

Kermit — Daniel, William Alexander (M).

Lake Jackson — Griswold, Nelson D. (M).

Lubbock — Henderson, Donald Lee (J).

Midland — Stephens, Robert Monroe (R, C/S-J-M).

Odessa — Hippard, Robert Mark (M).

San Antonio — Green, Guy E. (M); Magne, Louis E. (M); Swearingen, Judson S. (R, M).

Stinnett — Hanna, Harry C. (J).

Wichita Falls — Garlick, James Maurice (M); Magee, James Foster (J); Reavis, Harley Neal (M).

Canada

Calgary, Alta. — Blackmore, Harvey Francis (M); Holmberg, Hjalmar Branting (M).

Mexico

Coatzacoalcos, Ver. — Prian, Ricardo Caletti (J).

Persian Gulf

Awali, Bahrain — Cotter, William Hingston (M).

Peru

Lima — Bonillas, Ygnacio (M).

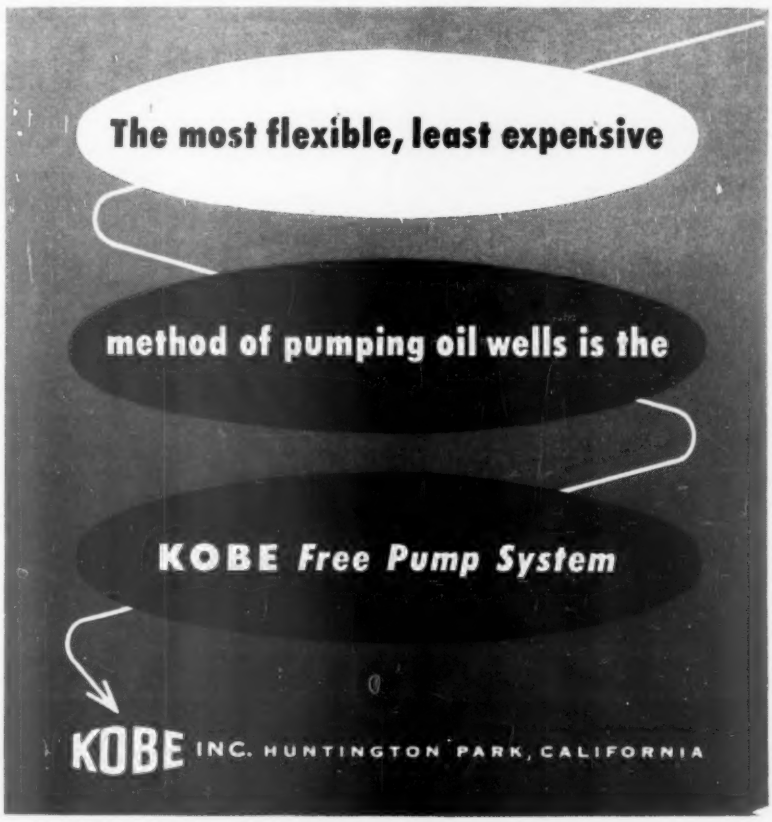
Kirkendall To Assist E. O. Robie; Recommended As Next Institute Secretary

E. O. Kirkendall was named administrative assistant secretary of the AIME by the Board of Directors at their Sept. 21 meeting. This move was made in line with the approaching retirement of AIME Secretary Edward H. Robie.

The Board has recommended to the "new" Board taking office in February that Kirkendall at that time be made secretary of the Institute, and that Robie be made secretary emeritus for the ensuing year, with duties to be assigned.

Since January 1946 Kirkendall has been assistant secretary of the AIME and secretary of the Metals Branch and its constituent divisions. He is 40 years old and holds a BS degree from Wayne University, and MS of Michigan. For 10 years he taught metallurgical and chemical engineering at Wayne University.

Since coming to the Institute he has been instrumental in organization of the Extractive Metallurgy Div. in 1948, the Metals Branch in 1949, and the inauguration of the Journal of Metals in 1949.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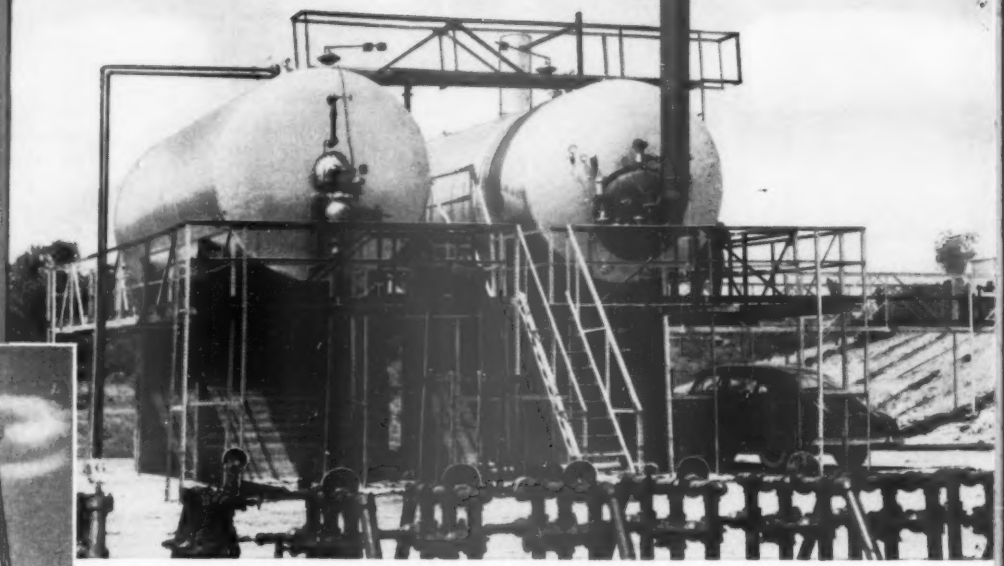

This BS&B installation near Gladewater, Texas, is an example of how large volume treating requirements may be handled. It consists of a BS&B Special Free Water Knockout and a BS&B Special HGT 1028 Horizontal Treater, with a capacity of 30,000 bbls./day. Standard sizes of the HGT will meet capacity requirements ranging from 100 to 4800 bbls./day.

There's a BS&B Emulsion Treater of the Right Size and Type for YOU!

Oilfield requirements for emulsion treaters vary widely from lease to lease and climate to climate. Some situations call for horizontal treaters — some for vertical; some for small capacity — some for large; some for extremely cold weather operation — some for more moderate or very hot climates. Treating problems may be relatively simple — others extremely difficult.

But *no matter what* your treater requirements ... BS&B has a treater that will meet them *perfectly*, and which will give years of efficient and trouble-free service. "Down time" for maintenance or repairs will be *considerably less* than for most other makes of treaters.

If you haven't enjoyed the satisfaction of operating a BS&B Emulsion Treater on your lease, we'd suggest you get the facts from your BS&B Man. Or, write for catalogs and information. There's no obligation!

This BS&B Type "J" Vertical Treater installation is typical of many that are handling particularly tough treating problems throughout the oil country. Depending on treater size, the Type "J" will meet capacity requirements of from 100 to 3600 bbls./day. Type "JCW" is similar to the Type "J", except that it has several additional features which fit it for operation in extremely cold climates.

For low cost treating under average conditions, BS&B Type "S" Vertical Treaters like this one perform excellently. It has a capacity range of from 100 to 2500 bbls./day, depending on the size of the treater. The Type "SCW" is structurally the same as the Type "S", except for modifications to adapt it to cold weather operation.

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Nominating Committee for AIME Officers in 1955 Named

The following have been named by the Council of Section Delegates, the Branch Councils, and the President of the Institute to constitute the Nominating Committee for AIME Officers in 1956. The Committee will meet during the Annual Meeting of the Institute in Chicago, Feb. 14 to 17, 1955 and select the official slate. If the principal finds it impossible to attend, the alternate will act in his place; otherwise the alternate will not be present at the meeting of the Committee. The names of the alternates are given in parentheses.

President Reinartz's Appointments: Edward G. Fox, Chairman, Philadelphia & Reading Coal & Iron Co., Philadelphia, Pa. (Frank Ayer, New York, N. Y.); Charles E. Golson, Colorado Fuel & Iron Corp., Denver, Colo. (Wayne Dowdey, Eimco Corp., Birmingham, Ala.); Richard M. Foose, Franklin & Marshall College, Lancaster, Pa. (Theron W. Reed, Owens-Corning Fiberglas Corp., Newark, Ohio).

Mining Branch Council: H. M. Bannerman, U. S. Geological Survey, Washington, D. C. (E. P. Pfleider, University of Minnesota, Minneapolis, Minn.); E. H. Crabtree, U. S. Atomic Energy Commission, Grand Junction, Colo. (Ian Campbell, California Institute of Technology, Pasadena, Calif.).

Metals Branch Council: Robert F. Mehl, Carnegie Institute of Technology, Pittsburgh, Pa. (H. H. Kellogg, Columbia University, New York, N. Y.).

Petroleum Branch Council: Claude R. Hocott, Humble Oil & Refining Co., Houston, Tex. (Paul R. Turnbull, Del Mar Drilling Co., Corpus Christi, Tex.).

Council of Section Delegates, Executive Committee: Roger V. Pierce, Salt Lake City, Utah (H. R. Gault, Lehigh University, Bethlehem, Pa.).

District 1, New York: James S. Vanick, International Nickel Co., New York, N. Y. (John H. Ffolliott, Miami Copper Co., New York, N. Y.).

District 2, Connecticut: W. E. Milligan, Hammond Metallurgical Laboratory, New Haven, Conn. (Leon W. Thelin, Chase Brass & Copper Co., Waterbury, Conn.).

District 3, St. Louis: Jack H. McWilliams, Aluminum Co. of America, Bauxite, Ark. (Carl H. Cotterill, American Zinc, Lead & Smelting Co., St. Louis, Mo.).

District 4, Pittsburgh: Hugo E. Johnson, Lake Superior Iron Ore Assn., Cleveland, Ohio (John C. Calhoun, Pennsylvania State University, State College, Pa.).

District 5, Chicago: R. A. Lindgren, International Harvester Co., Chicago, Ill. (C. T. Hayden, Sahara Coal Co., Chicago, Ill.).

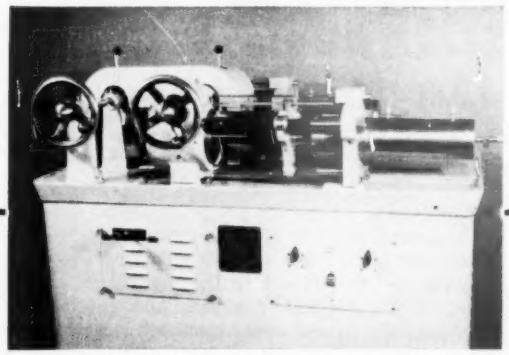
District 6, Black Hills: James O. Harder, Homestake Mining Co., Lead, S. D. (Max W. Bowen, Golden Cycle Corp., Colorado Springs, Colo.).

District 7, Oregon: D. W. Johnson, Reynolds Metals Co., Troutdale, Ore. (Thomas J. Waters, Carbide & Alloys Co., Portland, Ore.).

District 8, Southern California: Basil Kantzer, Union Oil Co. of California, Los Angeles, Calif. (Ian Campbell, California Institute of Technology, Pasadena, Calif.).

District 9, Carlsbad Potash: George E. Atwood, Duval Sulphur & Potash Co., Carlsbad, N. M. (C. E. Presnell, International Minerals & Chemical Corp., Carlsbad, N. M.).

District 10, Delta: Byron L. Francis, Texas Co., New Orleans, La.



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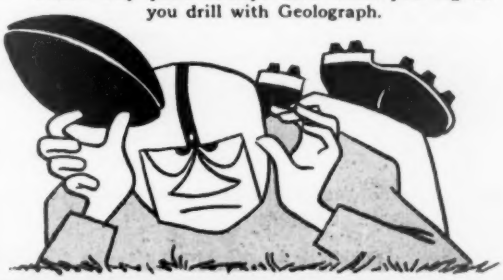

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To AIME Members

SERVICES OFFERED by THE ENGINEERING SOCIETIES LIBRARY

Recently the Petroleum Branch office in Dallas received a telephone call from a member who wanted to obtain several copies of a paper appearing in the 1944 volume of *Petroleum Transactions*. No reprints of this paper were readily available at the Dallas office; therefore, the member was informed of the photostat services of The Engineering Societies Library in New York. He contacted this library and received photostatic copies quickly.

This incident is repeated often at the Dallas office, for many AIME members are not aware of their privilege of using the services of The Engineering Societies Library at discount prices.

The library prepares bibliographies and translations, and provides search, photostat, and microfilm services. Members of the AIME who order work for their personal, not company, use receive a discount of 20 per cent on searches and translations, and of five cents on each photoprint.

Another privilege of AIME members is to borrow books from this library for the payment of a small handling charge only. The library now consists of 170,787 volumes covering all branches of engineering, primarily on the level of the graduate or practicing engineer, as well as 16,301 maps and 5,457 searches.

The primary rules applying to the loan of books are: (1) bound books may be borrowed by any member in good standing residing in the United States or Canada, (2) the charge is 50 cents per week, (3) and two weeks is the maximum length of the loan, discounting, transit time.

For the fiscal year ended Sept. 30, 1954, 16,817 visitors were served, and 21,278 non-visitors by the Library. Orders for photoprints increased to 4,704. Close to 10,000 telephone inquiries were answered and some 4,800 written replies to inquiries. A total of some 260,000 words were translated.

From time to time the JOURNAL OF PETROLEUM TECHNOLOGY publishes reviews of books available at The Engineering Societies Library. When members desire to borrow the books listed, they should contact Ralph H. Phelps, Director, Engineering Societies Library, 29 West 39th St., New York 18, N. Y.

Some of the books now available for loan are:

World Petroleum Statistical Yearbook

Volume 1 : 1953/54 edition.

Edited by Henry J. Struth. Mona Palmer, 604 Fifth Avenue, New York 20, 1954. 452p., 11¼ x 8½ in, bound. $20.00.

Facts and figures accompanied by analysis of conditions and trends in the industry are supplied in this new directory. Three major divisions cover exploration, drilling, production, refining, transportation, and economics of petroleum and its products on a world scale, in the United States, and in foreign countries. Separate sections deal with taxation, employment, and investment and finance. There is a subject index.

Price Making and Price Behavior in the Petroleum Industry

(Petroleum Monograph Series, Volume 1)

By Ralph Cassady, Jr., Yale University Press, New Haven, Conn., 1954. 353p., 9½ x 6¼ in, bound. $4.50.

This monograph, the first in a series on the petroleum industry, deals with pricemaking procedures and results in the domestic market. Included in the study are an evaluation of the importance of petroleum in the economy; analysis of competition in the industry; detailed consideration of prices and pricing methods at the refinery, tank wagon, and retail level; and examination of the price structure as a whole in terms of interindustry price comparisons and profitability.

The Growth of Integrated Oil Companies

By John G. McLean and Robert Wm. Haigh. Harvard Business School, Division of Research, Soldiers Field, Boston 63, 1954. 728p., 11¼ x 8¾ in, bound. $12.00.

The emergence of large integrated oil companies as the predominant form of organization in the oil industry is the subject of this study. Part one depicts the structure of the industry in 1950; part two discusses the technological, economic and business factors which resulted in integration; part three analyzes seven representative companies to determine differences in structure and in managerial policies; part four examines the position of the small refiners in the industry.

The Power of Gas

A Complete Manual on Oil Production by Gas Lift.

By C. V. Kirkpatrick. Camco, Inc., 7317 Canal Street, Houston, Tex., 1953. 89p., 11¼ x 8½ in, paper. $5.00.

An evaluation of gas lift design problems and practices addressed to those without previous study in the field as well as to those with an advanced knowledge of the subject. In addition to the design and analysis of installations, gas law, reservoir, and gas measurement fundamentals and applications are treated.

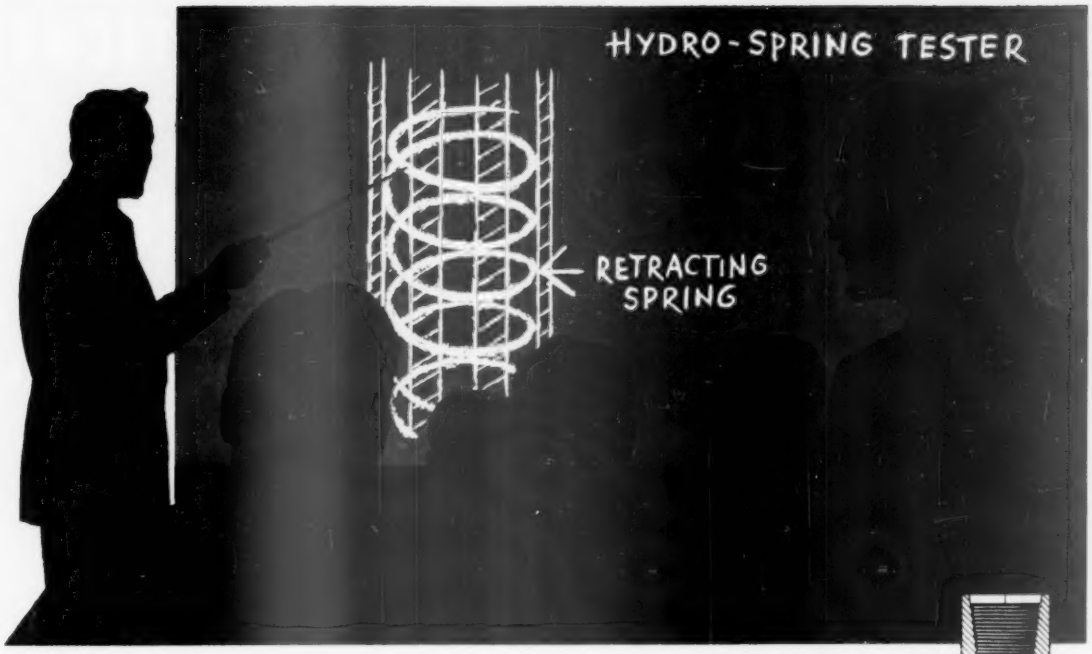
Condensate Well Corrosion

National Gasoline Association of America, 422 Kennedy Bldg., Tulsa, 1953. 203p., 9¼ x 6¼ in, bound. $6.00.

Describes the action of water solutions of carbon dioxide and fatty acid on corrosion of production equipment, and discusses various methods for control. Individual authors contribute chapters on inhibitors, types of tubing, metallurgical factors, and related subjects. A separate chapter is devoted to costs, and one chapter gives field histories of the experiences, studies, and remedial measures made in typical condensate well fields. References are cited after each chapter.

R. W. TAYLOR

★★★



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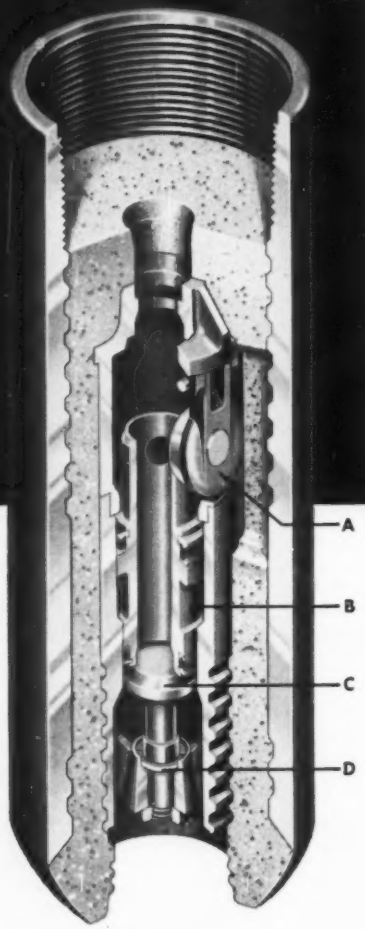

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A—Flapper Valve functions only at discretion of operator.
B—Sleeve Valve operates to control rate of flow and volume of "fill-up" fluid.
C—Sleeve Valve Seat.
D—Shear Ring is sheared. Flapper Valve now functions for floating or cementing.

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- **DIFFERENTIAL FILL-UP COLLARS**

Here's what DIFFERENTIAL FILL-UP Equipment does . . .

Permits the casing to *fill automatically from the bottom*, while it is being run, to within 90% of the fluid level of the annulus (using a shoe OR a collar)—or to within 81% of the fluid level of the annulus (using *both* a shoe AND a collar). In addition, a back-pressure valve is present to be used at the *discretion of the operator*, for "floating" or for cementing.

Here's how Baker DIFFERENTIAL FILL-UP Equipment will aid you to avoid danger, increase rig efficiency, save valuable time and promote safety...

REDUCES THE DANGEROUS "RAM EFFECT" thus minimizing the hazard of breaking down a potential lost circulation zone.

SAVES COSTLY DRILLING MUD that might otherwise be lost to the formation due to the "ram effect."

MINIMIZES DAMAGE TO MUD CAKE on the wall of the hole. The majority of the fluid displaced as the casing string is lowered enters the casing instead of flowing up the annulus and causing possible damage to the mud cake.

REDUCES DANGER OF STICKING CASING by reducing to a minimum the "no-motion time" formerly required to fill casing at the surface—extremely important when running casing in directional holes or sloughing formations.

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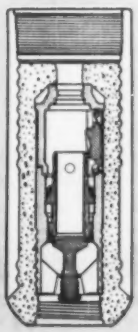
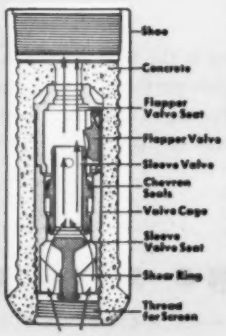
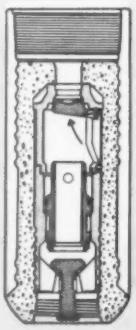


When running-in, the Sleeve Valve is in closed position in contact with the Sleeve Valve Seat. When the Sleeve Valve is in this position, fluid entry into the casing from below the valve is effectively blocked. The Sleeve Valve will be in the closed position whenever the height of the fluid column in the casing (the fill) EXCEEDS 90% of the height of the fluid column in the annulus.



When the height of the fluid column in the casing (the fill) is LESS than 90% of the height of the fluid column in the annulus, the Sleeve Valve moves upward away from the Seat and permits fluid entry into the casing through the bottom of the FILL-UP Shoe. During the casing run, the Sleeve Valve opens and closes according to the pressures imposed on its top and bottom areas and thus automatically regulates the degree of fill.



When it is time for cementing, pressure of approximately 1,000 psi is built up in the casing to shear the Shear Ring that holds the Sleeve Valve Seat in the supporting vanes of the Valve Cage. The Sleeve Valve can then move downward sufficiently to release the spring-loaded Flapper Valve, and thereafter the FILL-UP Shoe functions as a conventional Float Shoe.

EMPLOYMENT NOTICES

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 800 Fidelity Union Bldg., Dallas 1. These replies will be forwarded unopened and no fees are involved.

PERSONNEL

☆ Petroleum Engineer, 40, with approximately eight years experience in petroleum production, three years in evaluation, and two years in technical writing. Now employed but desires change. Code 225.

☆ Petroleum Engineer, 32, seeks reassignment, domestic or foreign, preferably with independent offering opportunity for advancement. Eleven years domestic and foreign experience—drilling, production, reservoir, supervisory. BS degree. Married, no children, now employed. Code 226.

☆ Petroleum-Natural Gas Engineer, 47, registered in Texas. Experience in the design, construction, and operation of cycling and gasoline plants, compressor stations (reciprocating and centrifugal), and gas and oil pipelines. Some Spanish. Prefers position in South America. Code 229.

☆ Petroleum and Natural Gas Engineer, 30, with 3½ years varied experience in petroleum and natural gas production. Seeks reassignment, domestic or foreign, preferably South America. Code 230.

☆ Petroleum Engineer, 32, with eight years experience in drilling and production engineering. Now employed. Seeking employment with company offering opportunity for advancement. Prefer California. Code 231.

POSITIONS

☆ Teacher for Petroleum Engineering subjects, preferably with Master's Degree. One-half time to be devoted to teaching and the remainder may be spent on work toward an advanced degree in science, engineering, or mathematics. Salary—$3,600 for approximately nine months. Send complete record to Department of Mining and Petroleum Engineering, The Ohio State University, Columbus 10, Ohio.

☆ Major Oil Company has openings for several reservoir engineers. Prefer one or two years reservoir experience with some background of field work. Excellent opportunities for advancement with aggressive organization. Code 566.

☆ Financial Institution seeks graduate petroleum engineer with several years experience in the field and some experience in valuation of oil and gas reserves, principally in Texas and adjoining states. Position offers experience in appraising oil and gas properties, and financing in the petroleum industry. State age, education, experience, and marital status. Code 567.

☆ Graduate Assistantships, available February 1 and July 1 in petroleum production engineering research on fluid flow in porous media at $131 per month. Research Assistantships in same field at $250 to $350 per month. Code 568.

☆ Petroleum Engineer, under 35, drilling and production work in Rocky Mountain area with compact but enterprising independent operator with excellent financial structure. Salary dependent upon experience and qualifications. Send detailed experience record. Code 569.

☆ Young PhD in petroleum or chemical engineering, preferably with some research experience, for responsible charge of sponsored research program in petroleum engineering. Splendid opportunity for publication and service to entire industry. Location, major university. Salary $7,500 to $8,500 per year depending upon qualifications. Reply giving full de'ails, age, experience, college transcripts, military status, and references. Code 570.

Hobbs Section Official Territory Is Released

Releases having been secured from Local Sections, a part of whose area has been taken over, the Hobbs Local Section was officially established at the October 27 meeting of the Executive Committee of the Institute. The Hobbs Section is an "overlaying" section to the extent that it covers the same ground as part of the Carlsbad Potash Section. Petroleum Branch members in this area of New Mexico (Eddy, Lea, and Chaves Counties) will henceforth be served by the Hobbs Section, and Mining and Metals Branch members by the Carlsbad Section.

Authors

(Continued from Page 52)

HARROLD D. OWEN received his BA degree in physics from Texas Christian University. At present, he is chief design engineer for Welex Jet Services, Inc., with whom he has worked since 1951. Prior to receiving his degree, he operated his own business for several years and later worked at Consolidated-Vultee Aircraft Corp.

J. OFFERINGA is a member of the reservoir engineering research team at Koninklijke/Shell-Laboratorium, Amsterdam. He was graduated in optics from Delft Technological University, The Netherlands, in 1951.

C. VAN DER POEL is a senior research engineer with the Koninklijke/Shell-Laboratorium in Amsterdam, Holland. Currently he is on a one-year assignment at the Shell Development Exploration and Production Research Laboratory in Houston. He was graduated from Delft University in 1942 and joined Shell in 1943.

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Publication Policies Established for 1955

Pursuant to Article X of the by-laws of the AIME, the following information is hereby given as to the "conditions, prices, and terms under which the various classes of members, and Student Associates, severally, shall be privileged to obtain publications of the Institute during the ensuing year."

Publications authorized for issue in 1955 include the following: MINING ENGINEERING, published monthly, containing material, including technical papers, of interest to those engaged in exploration, mining geology and geophysics; metal, nonmetallic, and coal mining and beneficiation; and fuel technology. The JOURNAL OF METALS, published monthly, containing material, including technical papers, of interest to those engaged in nonferrous smelting and refining, iron and steel production, and physical metallurgy. The JOURNAL OF PETROLEUM TECHNOLOGY, published monthly in Dallas, containing material, including technical papers, of interest to those engaged in petroleum and natural gas drilling and production.

Annual subscriptions to any one of the above journals will be provided all members in good standing without further charge, a subscription credit of $6 for members and $4 for Student Associates being included in the dues paid. (A member ceases to be in good standing if current dues are not paid by April 1). If more than one of the monthly journals is requested, $4 extra will be charged for an annual subscription, or 75 cents for single copies of regular issues and $1.50 for special issues. The nonmember subscription price for each journal is $8 in the Americas and U. S. possessions; foreign, $10, and for single issues 75 cents in the Americas and $1.00 foreign for regular issues and $1.50 for special issues. Student Associates will be entitled to the same privileges for all publications as members. AIME members subscribing to more than one of each of the three monthly journals will be billed at the nonmember rate of $8 per year, domestic; $10 foreign, for the extra subscription(s).

Three volumes of *"Transactions"* are authorized for 1955 publication, as follows: No. 199, Mining Branch; No. 200, Metals Branch; and No. 201, Petroleum Branch. Volumes 199 and 201 will be available to members at $3.50 each for a first copy if paid for in advance with dues; otherwise at the nonmember rate of $7 less 30 per cent. Nonmembers $7 in the United States; foreign $7.50. Volume 200 will be available to members at $4.50 each for a first copy if paid for in advance with dues; otherwise at the nonmember rate of $9 less 30 per cent. Nonmembers $9 in the United States, foreign $9.75.

If dues are paid subsequent to January 31, back issues of Institute publications will be supplied only if adequate stocks are on hand. A member is not entitled to receive a volume of *"Transactions"*, or a special volume, in lieu of a monthly journal, free of charge on membership. Members in arrears for dues are not entitled to special members' prices for publications.

Rocky Mountain Members may have their choice of an annual subscription to one of the monthly journals on request.

Dues for 1955 Payable

Pursuant to Article II, Section 2, of the by-laws of the AIME, notice is hereby given that dues for the year 1955 are payable Jan. 1, 1955, as follows: Members and Associate Members, $20; Junior Members for first six years of Junior Membership, $12, and thereafter, $17; Student Associates (including an annual subscription to a monthly journal), $4.50.

Dues bills were mailed during the latter part of November. Prompt payment will assure uninterrupted receipt of the publications desired in 1955. If, for any reason, a bill is not received within a reasonable time, headquarters should be notified.

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VOGTBORG NAMED WINNER OF THE RAYMOND AWARD

Harold Vagtborg, Jr., has been named the 1954 recipient of the Rossiter W. Raymond Award. This award is presented annually to the AIME member under 33 years of age who has published the best paper during the year. Vagtborg will receive his award at the annual AIME Meeting in Chicago on Feb. 14-17, 1955.

The title of the winning paper, which was published in the March issue of the JOURNAL OF PETROLEUM TECHNOLOGY, is "Equilibrium Vaporization Ratios for a Reservoir Fluid Containing a High Concentration of Hydrogen Sulfide." Not only the technological content but the proficiency of organization of the material and the literary style were criteria for judging the award winning paper.

Vagtborg is now with the National Bank of Commerce and Slick Oil Co. in San Antonio. At the time he wrote the paper, he was in charge of PVT studies in the Research and Development Laboratories of the Pure Oil Co., Crystal Lake, Ill. He holds a BS degree from the University of Kansas in mechanical engineering and a MS degree in petroleum engineering.

Other honors to be conferred at the annual banquet to be held on Feb. 16, 1955, at the Conrad Hilton Hotel are:

James Douglas Medal to Edwin Letts Oliver

Erskine Ramsay Medal to George Herman Deike

Robert W. Hunt Medal to F. W. Boulger and R. H. Frazier

J. E. Johnson, Jr., Award to Gust Bitsianes

Mathewson Gold Medal to W. G. Pfann

Robert H. Richards Award to Edward W. Davis

Peele Award to R. E. Thurmond and W. E. Heinrichs, Jr.

Engineering Foundation Sponsors Research for Offshore Drilling

Following endorsement by the AIME, Engineering Foundation has voted support to two projects of interest to the petroleum industry.

One, on "Forces Exerted on Oscillatory Fluid Motion on Cylinders," has to do with the effect of ocean waves on piles, and is of particular interest in connection with equipment and installations used in offshore drilling for oil. A grant of $1,500 has been made to D. L. Laird, of the University of California.

The other, "Phenomena Underlying Natural Disasters," is a proposed study which, if successful, would permit the accurate forecasting of tidal waves, or sudden unexpected onrushes of water. This, again, would be of value to offshore drilling crews. A grant of $5,000 for this study has been given to William L. Donn, of the Lamont Geological Observatory, Columbia University.

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